Proposed ADS-B MASPS Revisions: Intent Information Broadcast
RTCA SC-186, WG-6
Version 3.1, January 2001

1. Executive Summary: Proposed Intent Changes for DO-242A

WG-6 of SC-186 is currently preparing Revision A changes to the ADS-B MASPS for balloting in the near future. One of the major changes proposed for Revision A is a significant restructuring and expansion of the Intent parameters for future ADS-B systems. This document summarizes the reasons for the proposed Intent changes and provides a detailed overview of the proposed changes to DO-242 (Ref. 1), for critical review and comment prior to SC-186 balloting and adoption of DO-242A.

There are four~~three~~ primary changes proposed for Intent broadcast with DO-242A ADS-B systems:

- Introduction of Target State Reports (TSR's) for broadcasting current flight segment target states, i.e. target altitude and target heading / track angle,

- Adoption of a broader definition of Trajectory Change Points (TCP's) which includes 2-D RNAV waypoints, 3-D and 4-D trajectory change points under DO-242, and level-off changes in vertical transitions,

- Introduction of Trajectory Change Reports (TCR's) for broadcasting successive flight segment parameters and trajectory change points. (TCR's are the DO-242A equivalent of next TCP and TCP+1 reports in DO-242, but with an expanded report format for more generic TCP's, and capability for transmitting up to four TCP's.)

- Introduction of new transmission update rates and broadcast conditions for aircraft broadcasting TSR's and TCR's.

Target state reports provide intent information on autopilot target states such as the current or next intended aircraft level-off altitude, i.e. target altitude, and information on directional intent expressed as a target heading angle relative to the air mass, or as a target track angle relative to an inertial or ground reference frame. These parameters reflect short term tactical intent and are typically input by the pilot, e.g. as selected altitude for limiting a descent or climb transition, or as selected heading or track when flying in a tactical, less automated flight mode. Target altitude and target heading / track can also refer to the next intended targets flown by an autopilot in more automated modes such as RNAV and FMS modes, or as an input constraint to hold and maintain the current altitude or heading states.

The Trajectory Change Point definition in DO-242 was changed to accommodate a greater range of intent information, and to better reflect operational use and capabilities of existing and future aircraft avionics. The proposed TCR's allow for much greater flexibility in specifying intent information than the TCP's in DO-242, and provide a more comprehensive report structure for development and evolution of future ADS-B applications, e.g. trajectory conformance monitoring. TCR's include new parameters such as TCP Type to interpret the trajectory segment and change report data, and new parameters such as track-to-TCP, track-from-TCP, and turn radius as needed for trajectory segment predictions, e.g. for representing Fly-By turns consistent with FMS data outputs.

2. Introduction

The reason for considering broadcast of Intent information in ADS-B systems is to extend the domain of predictability of aircraft trajectories beyond short term extrapolations using current aircraft position and velocity states. Most current ADS-B applications under development only require state vector data. However, future applications of ADS-B could require intent information to extend lookahead time for trajectory predictions beyond the current flight segment, or as a means of enhancing integrity of extrapolated path predictions. Proposed air-air applications of intent information include airborne separation planning where more than a few minutes lookahead time is desirable for conflict detection and conflict prevention, and conflict resolution, where broadcast of intended resolution maneuvers may be important for situation awareness of all nearby equipped aircraft. ADS-B intent information is also proposed to enable advanced air-ground applications such as sequencing and merging of terminal area flow streams, and use of precision trajectory separation concepts for aircraft arrival and departure flows in congested airspace.

The type of intent information considered for ADS-B broadcast is limited to generic trajectory segment information that does not require detailed knowledge of airplane avionics, e.g. the use of standard lateral leg types for horizontal flight segments, and the use of climb, cruise and descent flight segments with specified end-points for vertical flight transitions. The overall objective is to describe intended trajectory segments in a generic way, avoiding the use of airplane specific guidance implementations and control modes.

The current ADS-B MASPS specify only a limited range of intent information, i.e. the use of 3-D and 4-D TCP's as endpoints of the current and next flight segment, respectively. Several reasons have been advanced for expanding the use of intent beyond that in the current MASPS:

(1) The current ADS-B TCP's need revision to reduce ambiguity in representing and predicting flight trajectories. One problem with the current MASPS is that TCP's alone do not adequately describe either the current intended trajectory segment, or the intended trajectory change at the endpoint TCP.

(2) ADS-B Intent should better reflect the operational capabilities of existing and future aircraft avionics systems, i.e. to represent autopilot target values when flying in less automated tactical modes, and to include a wide range of aircraft automation systems ranging from current 2-D RNAV systems to existing and future FMS-based precision RNP RNAV systems.

(3) ADS-B systems need expansion to better reflect longer term intent, i.e. beyond that represented by next and next+1 TCP's. Some operational concepts advanced for ADS-B could require trajectory prediction times in excess of ten minutes lookahead or longer. Moreover, trajectory changes may occur quite frequently in the terminal area and more TCP's are required than in en-route applications for short term separation and flow

planning. The proposed changes are also consistent with recently formulated Eurocontrol ADS-B requirements (Ref. 2).

The proposed ADS-B Intent revisions summarized in this document address the above issues. The proposal summarized here is based on inputs from several SC-186 groups and on inputs from European standards bodies, with substantial filtering and harmonization of inputs. The resulting proposal is intended to be a basis for current MASPS implementation, and to serve as an incremental basis for future development of ADS-B applications.

3. Scope of Revision A Intent Proposal

One of the challenges in developing and evolving intent information for ADS-B, is that most current aircraft avionics, including many advanced digital FMS-based systems, do not output much intent information on avionics buses for downstream use by avionics other than those directly used to communicate to the pilot or to navigate, guide, or control an airplane. In this proposal, we deal with this situation in two ways: (1) allowing aircraft which output some intent information to communicate such intent when appropriate through the TSR and TCR formats, and (2) providing intent provisioning in the report formats for future evolution and introduction of more comprehensive intent data. In short, Revision A provides an incremental approach to intent broadcasting, which allows for partial broadcasting of limited intent in Revision A, with evolution to more comprehensive intent data on both an individual aircraft basis as avionics systems are upgraded, and with further intent evolution anticipated in future Revisions to the ADS-B MASPS.

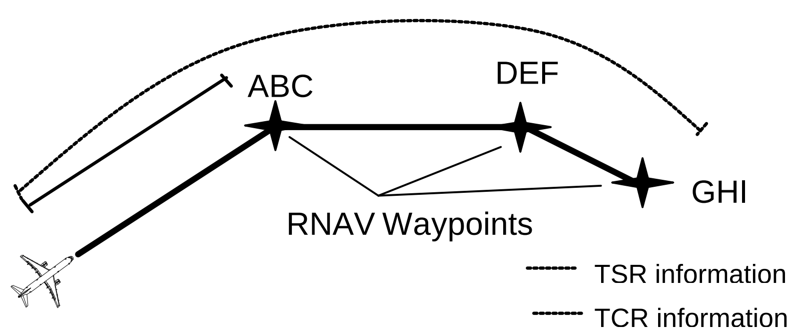
The newly proposed TSR's allow for broadcast of next intended *Target* level-off altitude, and *Target* heading or track data used for current path guidance. Since full implementation of Target state data may depend on FMS or autopilot mode information not currently available on any avionics bus, Revision A allows for partial implementations of Target states based on information which is available for input to an ADS-B transmit system. For example, if only autopilot-based Selected Altitude is available for TSR reporting, then it is allowed to broadcast such information with appropriate status indicators, even if the next intended level-off of the aircraft may be an unknown FMS target value. However, the fact that the aircraft is only capable of broadcasting Selected altitude and autopilot modes is transmitted in the TSR, to avoid interpreting Selected altitude as the probable next level-off state.

The TCR's proposed for Revision A consist of a number of horizontal and vertical flight segment and TCP types which are commonly used, have standard segment and TCP parameters, and are available as potential outputs on an ARINC data bus, e.g. the 702A trajectory bus (Ref. 3). The horizontal flight segment types include Course-to-Fix (CF), Track-to-Fix (TF), and Direct-to-Fix (DF) leg types, and Fly-By and Radius-to-Fix (RF) turn segments. (See section 9 for further explanation of these leg types.) Fly-over turns can also be modeled by appropriate use of the above leg types in conjunction with a DF or TF flight segment to model the turn transition to a specified end-fix. The vertical flight segments include initial climb to Top-of-Climb, flight at cruise altitude to Top-of-Descent, i.e. start of the descent phase, and some level-off transitions. In addition, target altitude as the intended end of a vertical transition is allowed as a TCP. RNAV systems that only output 2-D TCP's are also allowed, i.e. the vertical TCP components are marked as "not-available".

Some parameters and leg types that are important for intent broadcast and that are not currently available as inputs on a data bus, or are not sufficiently developed, are provisioned in the TSR and TCR's, but are not fully implemented in Revision A. This includes TSR and TCR operational validity for intent reporting, altitude constraint parameters ("At" and "At and Above/Below"), and leg parameters such as turn radius which may not be available for some RNAV / LNAV systems. The validity data would provide guidance system status for TSR target values, and navigation system conformance for TCR reports and are considered essential for critical separation assurance applications. Current FMS / VNAV systems provide the ability to specify altitude constraints at specified waypoints or fix locations which may constrain the FMS planned vertical trajectory. Broadcasting of such constraints is important for predicting vertical trajectory level-offs and changes in vertical path to meet such constraints. However, these constraint points are not generally available from FMS systems, and are not available on an ARINC data bus today. Consequently, these parameters and leg types are to be provisioned for later version ADS-B MASPS adoption.

4. Short and Long-term Intent

Target State Reports (TSR's) are implemented in DO-242A in order to provide information about the aircraft's active flight segment. The <u>*active*</u> flight segment refers to the current path and automation states being used for guidance and control of the aircraft. The primary elements of the TSR include the target altitude and target heading or track angle for the active flight segment. This information is called short-term intent. TSR's provide these intent elements even in cases where no TCP exists or TCP information is only partially available. Long-term intent includes information about TCP's and connecting flight segments, and is provided in a series of Trajectory Change Reports (TCR's). Figure 1 shows the relationship between information provided in TSR's and TCR's for an aircraft flying a simple trajectory between RNAV waypoints. The target track to waypoint ABC and the target altitude for the active flight segment are provided in the TSR. Three TCR's give information on waypoints ABC, DEF, and GHI. Note that this figure only represents one type of trajectory. Other trajectory types and the information used to fill the TSR and TCR's (if available) are described in the following sections.



<u>Figure 1</u>: TSR and TCR Information

The amount of intent information available for data exchange depends in large part on the transmitting aircraft's current control state and equipment. The three primary control states, referred to here as manual (no flight director), target state, and flight plan, are shown in Figure 2. With each additional outer loop, it is possible for an aircraft to communicate more information about future states and flight segments. While operating with target state control, one commanded state is available for the horizontal and another for the vertical axis, respectively. This information is provided in the TSR. In the outermost loop corresponding to flight plan control, the aircraft has knowledge of multiple trajectory change points and connecting flight segments. TCR's provide this information. In the flight plan control state, the TSR provides target state information corresponding to the active flight segment.

Most commercial aircraft have several flight modes corresponding to the target state and flight plan control states shown in Figure 2. Flight modes are normally selected through the Mode Control Panel or Flight Control Unit. They include choices such as hold current heading, hold current altitude, and maintain track between RNAV waypoints. The pilot can concurrently choose lateral and vertical flight modes that correspond to different control states, leading to different intent availability in the horizontal and vertical axes. Horizontal and vertical flight commands may be generated for manual flight using a flight director display mode, rather than through direct autopilot commands. In this paper we do not distinguish between flight director and autopilot operation, since this information cannot be differentiated from ADS-B output reports.

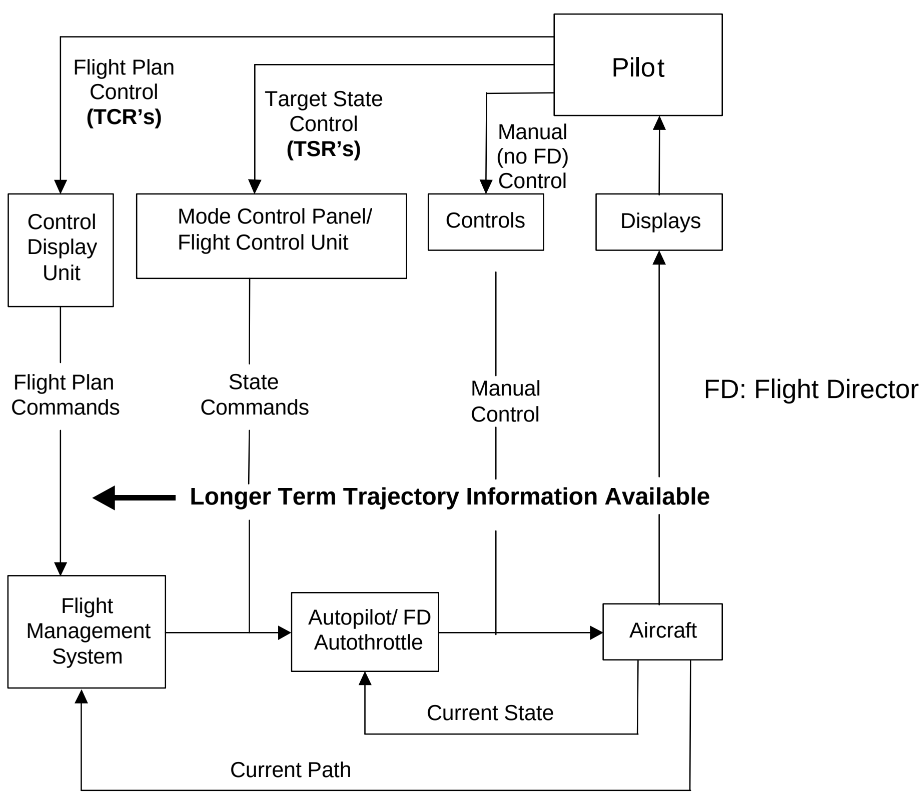


Figure 2: Aircraft Control States

Figure 2 shows typical equipment available on transport category aircraft that is capable of providing the associated information. Other flight hardware may also be able to generate this information. More sophisticated equipment is needed to transmit outer loop information, although inner loop information on current target states may be difficult to transmit for older analog aircraft. A Mode Control Panel (MCP) or Flight Control Unit (FCU) is the primary interface between the pilot and autopilot when not operating in FMS automated modes. These interfaces allow the pilot to select target states such as altitude, heading, vertical speed, and airspeed. Since only the next target state is allowed in each axis, pilots often use the MCP or FCU for short-term tactical flying. Conversely, the Flight Management System (FMS) allows the pilot to specify a series of target states or flight segments through a keypad-based Control Display Unit (CDU). A pilot may program an entire route complete with multiple waypoints, speed, altitude, and time restrictions, and specify desired speed and altitude appropriate to the current flight segment. Because the FMS allows definition of consecutive flight segments, it is frequently used for long-term strategic flying.

Complex paths may be created when an aircraft's trajectory is generated with both MCP/FCU and FMS targets. Such a situation can occur when the lateral and vertical modes correspond to different control states, when FMS-based modes are armed prior to activation, or when an autopilot target value affects an FMS planned trajectory. The latter case is most common when the MCP/FCU selected altitude lies between the aircraft's current altitude and the programmed FMS altitude, i.e. cruise altitude or altitude constraint. In this case, the aircraft will level out at the selected value, i.e. selected altitude acts as a limit value on the planned climb or descent.

Both short (TSR) and long-term (TCR) intent information offer a potential benefit to airborne conflict management, separation assurance, surveillance, flight plan consistency, and conformance monitoring applications. Short-term intent is available in almost all flight modes, while 4D TCP's are only available when equipped aircraft are using sophisticated FMS and area navigation (RNAV) systems.

5. Target State Reports (TSR's)

Short-term intent parameters are assembled in the TSR shown in Table 1. The first three elements of the TSR are the data fields that are common to all ADS-B reports, i.e. participant address, address qualifier, and time of applicability. The principal elements of this report are the target altitude and target heading or track. These parameters represent the transmitting aircraft's vertical and horizontal target states and will also be included in the Trajectory Change Report if they are part of a TCP. If the aircraft is capable of broadcasting autopilot and all FMS vertical targets, then *target altitude* is the aircraft's intended level-off altitude if in a climb or descent, or the aircraft's current intended altitude if it is being commanded to hold altitude. This definition is consistent with that adopted by the European Downlink of Airborne Parameters (DAP) program (Ref. 4). If the aircraft is only capable of broadcasting autopilot targets, then an acceptable substitute for target altitude is the autopilot Selected Altitude or Holding Altitude depending on the target source indicator. A partial FMS capability, where only certain FMS targets such as intended cruise altitude are available, is also supported.

Target heading is provided if the aircraft is actively being controlled to an air reference heading angle (such as a Heading Select or Heading Hold mode). Target track is used if the aircraft is controlled to a ground or inertial reference track angle, such as when flying between waypoints on a flight plan. A single bit specifies whether the aircraft is controlled to heading or track angle. A bit is also reserved to indicate whether Target Heading / Track is an autopilot selected value, or whether Target Heading / Track is the verified guidance target for the current flight segment.

Table 1: Target State Report

Element #	Contents	Anticipated Resolution or Number of Bits
1	Participant Address	24
2	Address Qualifier	4
3	Time of Applicability	1 s
4	Data Available (Vertical)	1 bit
5	Target Altitude	100 ft
6	Target Altitude Type	1 bit
7	Target Altitude Capability	2 bits
8	Target Source Indicator (Vertical)	2 bits
9	Mode Indicator (Vertical)	1 bit
	(Reserved for Vertical Conformance)	1 bit
	(Reserved for future growth)	1 bit
10	Data Available (Horizontal)	1 bit
11	Target Heading / Track	1 degree
12	Heading / Track Indicator	1 bit
13	Target Source Indicator (Horizontal)	2 bits
14	Mode Indicator (Horizontal)	1 bit
	(Reserved for Horizontal Conformance)	1 bit
	~~(Reserved~~(-Reserved forTarget Heading/ Track Capability)~~for future growth)~~	1~~2~~ bit~~s~~
	(Reserved for future growth)	1 bit

Horizontal and vertical data availability bits indicate that target heading/track and target altitude are being reported and data reports are filled with currently relevant information. (Note: if TSR intent data is not received within a specified ‘coast time’, then those data fields not recently updated are marked ‘not available’).

Target Altitude Type indicates whether the target altitude is an MSL altitude or a Flight Level. It is assumed that the local transition level is known to the transmitting aircraft and that the target altitude is MSL or a Flight Level depending on whether the target altitude is below the transition altitude or not.

Horizontal and vertical target source indicators describe the aircraft system providing the corresponding target state. Options include the FMS, MCP or FCU selected values, or holding the aircraft’s current state. In cases where the aircraft is acquiring a target altitude common to the MCP/FCU and FMS, the target source indicator should declare the target to be the former, i.e. MCP selected altitude rather than an FMS target altitude since MCP selected altitude has limiting authority over the FMS altitude.

Horizontal and vertical mode indicators provide status information on whether the aircraft is acquiring (transitioning toward) the target state or is capturing or maintaining the target. (In the vertical plane, the FMS changes mode when 'capture' of a target altitude occurs. There may or may not be a subsequent guidance mode change when maintaining the target altitude.) These parameters are expected to increase integrity of predicted trajectory changes and to be useful for trajectory conformance monitoring.

Space is reserved for horizontal and vertical conformance validity. These bits would provide indications of pilot or autopilot conformance to target values. Conformance to vertical and horizontal target states are under consideration, but cannot be implemented in Revision A due to data source availability issues. These bits would determine whether the aircraft is being controlled in the direction of its flight director or autopilot command. In addition, several bits are reserved in the TSR report for future growth.

Consider the example shown in Figure 3. An aircraft climbs at constant vertical speed toward the MCP/FCU selected altitude of 8,000 ft while flying a constant 090 heading. TSR values for the intent elements 4-14~~5~~ are provided in Table 2. Both of the targets are resident in the MCP, as indicated by the target source indicators. The mode indicators show that the aircraft is maintaining the target heading and is acquiring, but has not yet captured, the target altitude. The target heading and target altitude are available and considered reliable, as provided by the availability indicators.

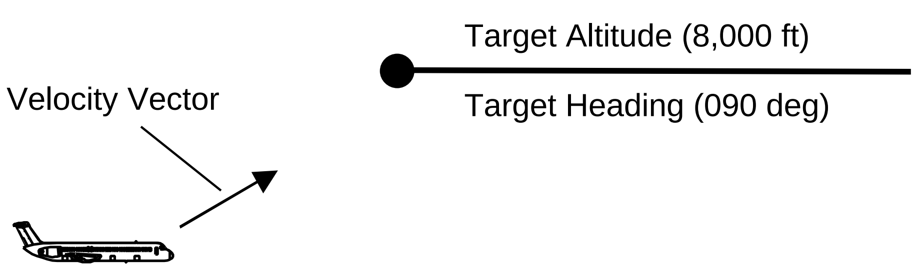


Figure 3: Constant Vertical Speed Climb at Constant Heading to MCP/FCU Selected Altitude

Table 2: Target State Report Elements for Figure 3

Element #	Contents	Example Values
4	Data Available (Vertical)	Available
5	Target Altitude	8,000 ft
6	Target Altitude Type	MSL

7~~6~~	Target Altitude Capability	Vertical Autopilot
8~~7~~	Target Source Indicator (Vertical)	MCP Selected
9~~8~~	Mode Indicator (Vertical)	Acquiring
10	Data Available (Horizontal)	Available
11	Target Heading / Track	090 deg
12	Heading / Track Indicator	Heading
13	Target Source Indicator (Horizontal)	MCP Selected
14	Mode Indicator (Horizontal)	Maintaining

In another example, the aircraft in Figure 4 is turning to join a 040 course (track) to the ABC waypoint. It is holding its current altitude (15,000 ft). TSR values are provided in Table 3. The target source indicators show that the target track comes from the FMS, while the target altitude is the MCP selected altitude. The aircraft is acquiring the horizontal target and maintaining the vertical target. Mode indicators show that horizontal and vertical target information is available.

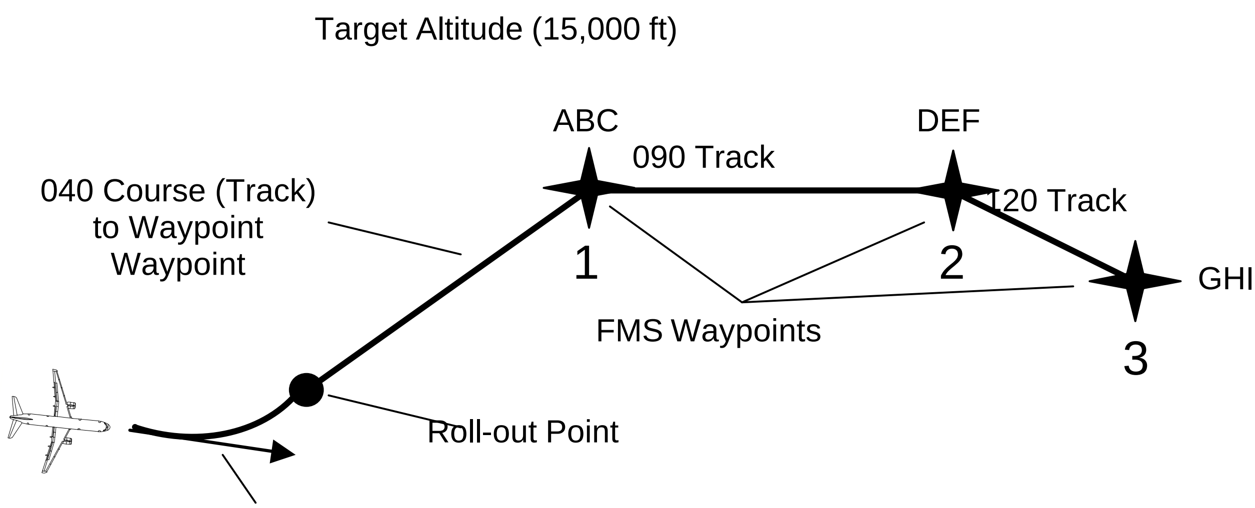


Figure 4: Intercept Course to FMS Flight Plan at Constant Altitude

Table 3: Target State Report Elements for Figure 4

Element #	Contents	Example Values
4	Data Available (Vertical)	Available
5	Target Altitude	15,000 ft
6	Target Altitude Type	MSL
7~~6~~	Target Altitude Capability	Vertical Autopilot
8~~7~~	Target Source Indicator (Vertical)	MCP selected altitude
9~~8~~	Mode Indicator (Vertical)	Capture/Maintaining
10	Data Available (Horizontal)	Available
11	Target Heading / Track	040 deg
12	Heading / Track Indicator	Track
13	Target Source Indicator (Horizontal)	FMS target

14	Mode Indicator (Horizontal)	Acquiring

As described above, the target altitude and target heading/track provide horizontal and vertical target states for the active flight segment. Information subsets are allowed for aircraft incapable of providing these target states. MCP/FCU selected altitude and selected heading may be used in place of target altitude and target heading/track, respectively. Likewise, aircraft equipped with only an RNAV system may provide the RNAV track angle in place of the target heading.
In order to provide a target state value, aircraft must be equipped with an autopilot or flight director that controls the axis consistent with the target value. The flight director must be on or the autopilot engaged while target state values are broadcast.

6. Trajectory Change Point (TCP) Definition

Further investigation into the many types of TCP's that can occur along an operational trajectory has led to a proposed TCP definition change for DO-242A. The current definition (DO-242, p. 39) only accommodates TCP's at a known 3D position in space. Although a 3D location is known for FMS waypoints, many flight segment changes do not occur at a known point. For example, an aircraft may be climbing in a constant vertical speed mode towards a target altitude (Figure 3). In this case, the aircraft may not take actual wind conditions into account when predicting the level-off location. Level-off prediction in a climb may also depend on changing aircraft performance. These uncertainties make it difficult to predict an accurate 3D intercept point. An analogous lateral situation may occur when an aircraft flies at constant heading to intercept a flight plan route. The intercept point is also dependent on wind parameters that may not be accurately known for intercept predictions. To account for these uncertainties, the following TCP definition is proposed: "<u>A Trajectory Change Point may be described as a 3D location or interception of a 2D plane with the aircraft's velocity vector where the current aircraft trajectory is intended to change</u>." Further details are provided in Appendix B.

Examples of TCP's under this definition include 2-D routing changes, the start and end points of a specified turn transition, FMS predicted Top of Climb and Top of Descent points, and target altitudes such as MCP selected altitude when currently in climb or descent transitions. A full list of TCP types included in Revision A is provided in Section 9. Future revisions may add additional TCP types that meet this definition.

In addition to TCP's, points involving an altitude constraint (At, At or Above, or At or Below) are provisioned for future revisions into the Trajectory Change Report, even if they may not involve a trajectory change. These points influence trajectory predictions even if no level-off occurs at the altitude constraint, and provide value for conformance monitoring applications.

7. Command and Planned Trajectories

The <u>*command* trajectory</u> refers to the path the aircraft will fly if the pilot does not engage a new flight mode nor change the targets for the active or upcoming flight modes. The command trajectory may include multiple flight mode transitions. Changes to the command trajectory normally result from a pilot input. However, a non-programmed mode transition may also occur that causes the aircraft to leave the command trajectory, e.g. reversion to speed priority on descent if the intended vertical path results in an over-speed condition.

The *planned* trajectory includes intent information that is conditional upon the pilot engaging a new flight mode. Without pilot input, the aircraft will only fly toward the command trajectory targets.

Figure 5 illustrates the difference between the command and planned trajectories for a simple descent scenario. In this case, the aircraft is flying a lateral and vertical FMS path that includes a planned altitude level-off at the End of Descent (E/D). The MCP/FCU selected altitude lies between the aircraft's current altitude and the E/D. Assuming the pilot doesn't change the aircraft's flight mode or targets, the aircraft will fly on the FMS descent path until reaching the selected altitude and then level off. This path is the command trajectory. If the pilot resets the MCP target at or below the E/D altitude prior to reaching the selected altitude, the aircraft will continue to fly along the FMS descent path and will level out at the bottom of descent. The programmed FMS path beyond the selected altitude represents a planned trajectory. Typically, selected altitude represents an ATC clearance altitude. In this case, the pilot may choose to fly directly to the end of descent as soon as a clearance to the planned altitude is received.

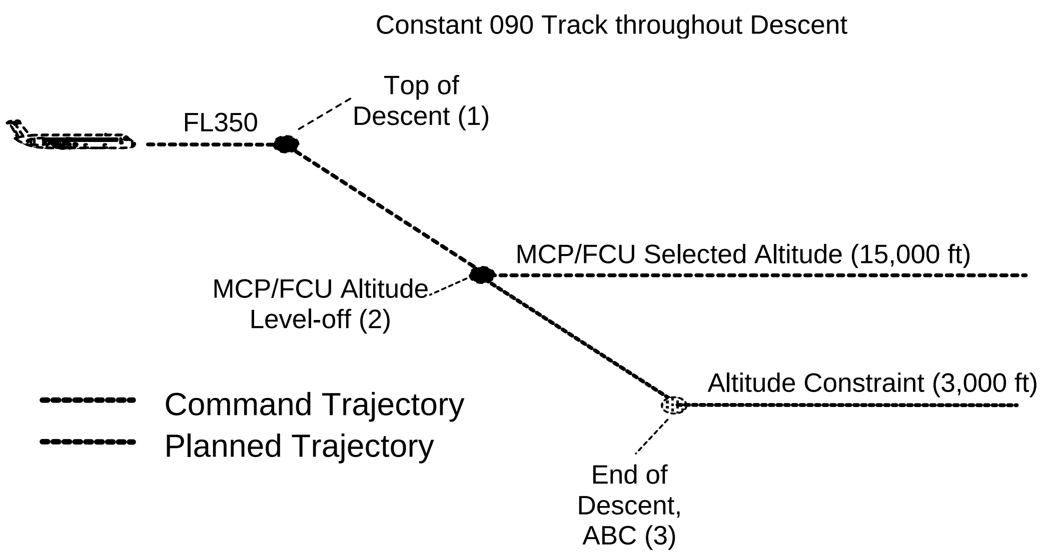


Figure 5: FMS Descent Showing Command and Planned Trajectories

These trajectory definitions are also expandable to aircraft sending intent information from non-FMS flight planning systems. For example, a LORAN or GPS navigation system on a general aviation airplane can be programmed to contain multiple waypoints. This path represents a planned lateral trajectory. It does not guarantee that the aircraft will fly that path, but represents information relevant to the pilot's long term plan.

Both the command and planned trajectories may provide useful information for separation assurance and flow management applications, respectively. In order to use this information effectively, the receiving system may need to delineate between the command and planned trajectories. This distinction is provided in the trajectory change report described below.

8. Trajectory Change Reports (TCR's)

Trajectory change reports replace the TCP's defined in DO-242. They provide an expandable structure capable of describing TCP's, waypoint constraints, and the flight segments that connect them. Many additional elements have been added to the DO-242 TCP report to facilitate path re-generation, data confidence assessment, and conformance monitoring. Some of the new parameters have been added to be consistent with ARINC trajectory bus specifications as reflected in Eurocontrol ADS Requirements (Ref. 2).

Table 4 shows the TCR structure. Not all elements are fully implemented in Revision A, but are included to show planned expansion as data becomes available. TCR fields are filled based on information availability aboard the transmitting aircraft and the TCP type.

Table 4: Trajectory Change Report

Element #	Contents	Anticipated Resolution or Number of bits
1	Participant Address	24 bits
2	Address Qualifier	4 bits
3	Time of Applicability	1 s
4	TCR sequence number (0, 1, 2, or 3)	2 bits
5	TCR Cycle number (0, 1, 2, or 3)	2 bits
6	Time to Go (TTG)	1 second
7	Data Available (Horizontal)	1 bit
8	TCP Type (Horizontal)	4 bits
9a	Latitude	0.1 minute[1]
9b	Longitude	0.1 minute[1]
10	Turn Radius	0.1 nmi[1]
11	Track to TCP	1 degree
12	Track from TCP	1 degree
13	(Reserved for Horizontal Conformance) [3]	1 bit
14	Command/Planned (Horizontal)	1 bit
15	Data Available (Vertical)	1 bit
16	TCP Type (Vertical)	4 bits
17	Altitude[2]	100 ft
18	Altitude Type	1 bit
19~~8~~	(Reserved for Altitude Constraint Type)	2 bits
20~~19~~	(Reserved for Able / Unable Altitude Constraint) [3]	1 bit
21~~0~~	(Reserved for Vertical Conformance) [3]	1 bit
22~~1~~	Command / Planned (Vertical)	1 bit

[1]Required resolution for future precision approach / departure applications may be higher. It is expected that new TCP types will be defined for applications with higher resolution requirements.
[2]Altitude estimate or altitude target, e.g. cruise altitude
[3]Only applies to active flight segment.

The first three elements of the TCR report are those common to all ADS-B reports, i.e. participant address, address qualifier and time of applicability. Note: time of applicability and time to go (element 6) need to be updated each time a TCR report is output. See Section 10 for a discussion of TCR "refreshment" when TCR intent information is not currently received.

The next three elements are parameters used for TCR report maintenance and data refreshment, i.e. updating a TCR report to the current time of applicability when no new data is received. TCR sequence number is the current sequence of TCP's for reconstructing the flight trajectory, i.e. TCP+0, TCP+1, TCP+2, TCP+3, respectively. TCR cycle number is a 2 bit code which increments whenever a major change in TCR intent occurs, such as sequencing the current TCP point. See section 10 for a detailed explanation of TCR cycle number and TCR report updating and maintenance. TTG is a required element for ~~horizontal~~all TCP's ~~and otherwise, whenever available~~. All TCR reports should have a unique sequence number, a common time of applicability and a common TCR cycle number at each report time. Intent data not updated within the 'coast time' specified in Section 10 are marked 'not available' and are not to be used until new intent data is received.

Elements 7 and 15 assess the availability and currency of horizontal and vertical TCP data. The associated horizontal and vertical data fields should not be used if they are reported unavailable.

The TCP type fields (elements 8 and 16) specify the flight segment and endpoint change type. Both a horizontal and a vertical TCP type are included to aid interpretation of the data elements for constructing path segments. In addition, it is feasible to have both a routing change and a vertical change or constraint at the same waypoint. The TCP type fields specify the way that the data received is to be interpreted, i.e. which elements are required for constructing the flight segment and endpoint conditions. Example TCP types are fly-by waypoint, direct-to-fix, and RF leg (lateral cases) and top of climb, top of descent, and target altitude (vertical cases). Section 9 describes the TCP types included in Revision A. Other types, including waypoint constraints, may be added to future revisions.

The availability of TCP horizontal position (elements 9a and 9b) depends on the transmitting aircraft's operating mode and equipment capability. These elements are provided if they are associated with a known waypoint or can be estimated by the FMS. These elements will have varying accuracy depending on TCP type. When using FMS lateral and vertical navigation, TCP's associated with waypoints can be estimated with high confidence. For TCP's which do not involve closed-loop control, such as top of climb, top of descent, or path intercepts, the latitude, longitude and time elements have higher uncertainty. Low integrity latitude/longitude predictions such as the "green arc" on Boeing aircraft that predicts altitude level-offs for MCP modes are not required, but TTG is required for any vertical TCP. These predictions can vary greatly if they do not compensate for wind and aircraft performance.

Figures 6 and 7 show the information needed for fixed radius and fly-by turns (Elements 10-12). Fixed radius turns include turn radius and start and end of turn points. Fly-by turns can also be described in this manner, however the alternate representation in Figure 7 is acceptable if the aircraft cannot provide start and end of turn points. In this case, the fly-by turn waypoint is provided, along with the track to and track from that point and the turn radius. Fly-over turns are represented in Revision A as a Direct-to or Course-to transition to the specified endpoint. For other horizontal TCP's, only the track to the TCP (Element 11) is provided.

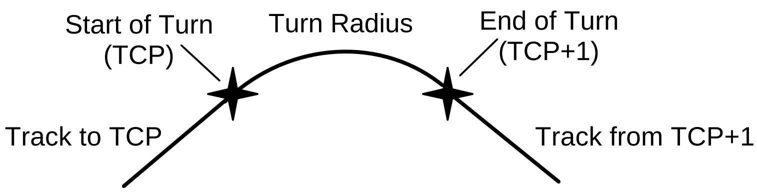


Figure 6: Fixed Radius or Fly-by Turn

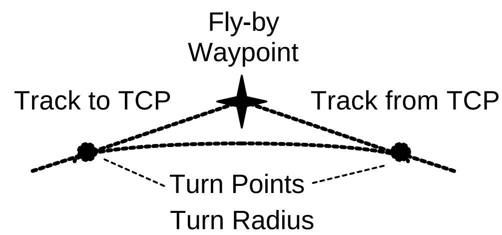


Figure 7: Fly-by Turn

Space is reserved for horizontal and vertical conformance (Elements 13 and 21~~0~~). These bits assess the conformance of the transmitting aircraft to its broadcast path. It is anticipated that future revisions may use horizontal and vertical RNP bounds to specify trajectory conformance. The conformance bits would broadcast the ability of the aircraft to conform to the specified trajectory bounds. For non-RNP aircraft, other measures of conformance may be specified.

Elements 14 and 22~~1~~ delimit whether the flight segment and TCP is part of the command or planned trajectory (see description in Section 7). Successive TCP's or altitude constraint points that are part of the command trajectory should be ordered as they are expected to occur, i.e. by TTG. In cases where time to go cannot be determined, no TCR is generated. ~~points having an altitude closest to the aircraft's current altitude are next in the TCR sequence.~~ If there is space available for additional points, planned TCP's can be included, but they should be placed at the end of the TCP list.

Elements 17 to 20~~, 18 and 19~~ specify the TCP altitude fields. Element 17 is the estimated or constraint altitude at the TCP, depending on vertical TCP type. Element 18 specifies whether the TCP altitude is referenced to MSL or Flight Level. Elements 19~~8~~ and 20~~19~~ are provisioned for future use. These elements can be used to indicate the type of altitude constraint ("At", "At or Above", "At or Below") and the transmitting aircraft's assessment of its ability to meet the altitude constraint. Altitude constraints may or may not be associated with a trajectory level-off, since the aircraft may be able to comply with the constraint without changing its trajectory. In the case that "window" constraints are specified, i.e. both "At or Above" and "At or Below" altitudes are specified, only one window constraint is reported. (See Appendix A.) Future DO-242 revisions may further expand TCR's to include speed and time constraints. Note: the "able / unable" altitude constraint flag (Element 20~~19~~) is different than the vertical conformance flag (Element 21~~0~~) since the former applies at a single point and the latter to an entire vertical segment.

Figures 4 and 5 are examples of horizontal and vertical FMS trajectories, respectively. The filled TCR elements corresponding to Figures 4 and 5 are given in Table 5 and Table 6, respectively. Both of these examples show how the TCR's would be filled for fully equipped aircraft able to support each element implemented in Revision A. It is expected that many current aircraft will not have these full capabilities, however these examples are provided in order to illustrate the application of a wide range of Revision A data elements. Figure 8 shows a more complex trajectory involving MCP/FCU and FMS targets. Tables 7a and 7b offer a comparison of TCR's for Figure 8 provided by fully and partially equipped aircraft, respectfully.

Figure 4 shows an aircraft turning to join a 040 course to waypoint ABC, followed by two routing changes at DEF and GHI. The roll-out point is not considered to be a TCP, since the intended path is a Course-to-ABC segment. After rolling out, it will join the FMS flight plan and fly to waypoints DEF and GHI. This example is flown at a constant altitude of 15,000 ft. All latitude and longitude fields are filled since all TCP's in this example are FMS waypoints. The aircraft is holding its selected 15,000 ft altitude, which is repeated for each TCP point. The end of the CF segment is the start of the Fly-By Turn, which is represented implicitly by the ABC waypoint and Fly-By turn radius. (In effect, the Fly-By Turn TCR implicitly represents both the CF track-to ABC segment and the Fly-By Turn at ABC to the next TF segment.) The straight line and turn segments for the other Fly-By turns are similarly represented implicitly, reducing the number of TCR's to represent the intended path.

Table 5: Trajectory Change Report Elements for Figure 4

Element #	Contents	TCR Values	TCR+1 Values	TCR+2 Values
4	TCR sequence number	0	1	2
5	TCR Cycle number	1	1	1
6	Time to Go (TTG)	TTG-ABC	TTG-DEF	TTG-GHI
7	Data Available (Horiz)	Available	Available	Available
8	TCP Type (Horiz)	CF and Fly-By	TF and Fly-By	TF and Fly-By
9a	Latitude	Latitude$_{ABC}$	Latitude$_{DEF}$	Latitude$_{GHI}$
9b	Longitude	Longitude$_{ABC}$	Longitude$_{DEF}$	Longitude$_{GHI}$
10	Turn Radius	Radius$_{ABC}$	Radius$_{DEF}$	Radius$_{GHI}$
11	Track to TCP	040 deg	090 deg	120 deg
12	Track from TCP	90 deg	120 deg	Track from GHI
13	(Reserved)	*	*	*
14	Command/Planned -H	Command	Command	Command
15	Data Available (Vert)	Available	Available	Available
16	TCP Type (Vertical)	Target Altitude	Target Altitude	Target Altitude
17	Altitude	15,000 ft	15,000 ft	15,000 ft
18	Altitude Type	MSL	MSL	MSL
19~~8~~	(Reserved)	*	*	*
20~~19~~	(Reserved)	*	*	*
21~~0~~	(Reserved)	*	*	*
22~~1~~	Command/Planned -V	Command	Command	Command

In Figure 5, the aircraft is flying in cruise at FL350, approaching the top of descent. The FMS cruise altitude is limiting and functions as the vertical target source. It has a single FMS altitude constraint at End of Descent (cross ABC at 3,000 ft). The MCP altitude is set to an intermediate value of 15,000 ft. Since the aircraft is limited by MCP altitude, it will level-off at 15,000 ft, given the current automation state. This path is the command trajectory. If the pilot resets the MCP altitude prior to reaching 15,000 ft, the aircraft will continue toward the End of Descent at ABC. ABC is included as a planned trajectory point. It has a known 3D location and the FMS time estimate may be provided.

Table 6: Trajectory Change Report Elements for Figure 5

Element #	Contents	TCR Values	TCR+1 Values	TCR+2 Values
4	TCR sequence number	0	1	2
5	TCR Cycle number	0	0	0
6	Time to Go (TTG)	TTG-TOD	TTG-MCP_ALT	TTG-ABC
7	Data Available (Horiz)	Available	Available	Available
8	TCP Type (Horiz)	Course-to-Fix	Course-to-Fix	Course-to-Fix
9a	Latitude	Est	Est	Latitude$_{ABC}$
9b	Longitude	Est	Est	Longitude$_{ABC}$
10	Turn Radius	X	X	X
11	Track to TCP	090	090	090
12	Track from TCP	X	X	X
13	(Reserved - Horiz)	*	*	*
14	Command/Planned -H	Command	Command	Command
15	Data Available (Vert)	Available	Available	Available
16	TCP Type (Vertical)	Top-of-Descent	Target Altitude	Estimate
17	Altitude	350~~FL350~~	15,000 ft	3,000 ft
18	Altitude Type	Flight Level	MSL	MSL
19~~8~~	(Reserved)	*	*	*
20~~19~~	(Reserved)	*	*	*
21~~0~~	(Reserved – Vert)	*	*	*
22~~1~~	Command/Planned -V	Command	Command	Planned

"Est": Element contents filled with FMS lat/long estimates, if available.

The TCR report provides flexibility for accommodating different TCP types and varying amounts of information available onboard the transmitting aircraft. The TCR report structure shown in Table 4 represents full reporting capability. Many aircraft may not be equipped to support all of these data elements

The following conditions govern the determination of TCR broadcast and command/planned status for each TCP. These conditions can be applied independently to the horizontal and vertical axis parameters:

1. If the transmitting aircraft does not have an autopilot or flight director engaged, then no TCR’s are generated. If the aircraft only supports a single axis autopilot or flight director, then the complementary axis data fields for TCR’s are marked “unavailable”.

2. A stable TTG must be obtained prior to generating intent messages for TCR reporting. A TTG value is considered “stable” if the estimated TTG based on past information is consistent with the current TTG value, i.e. the difference between the estimated and current TTG value is less than some threshold value. Specific rules for TTG stability will be determined during TCR format validation testing. See Appendix A.

~~2.~~3. If the transmitting aircraft cannot determine if a TCP is part of the command or planned trajectory, it must be labeled as “planned”. This determination must consider flight mode logic and targets resident in all auto-flight systems that support aircraft guidance.

~~3.~~4. If the transmitting aircraft cannot determine whether an intermediate TCP exists (as defined in Section 6) between the aircraft’s current position and a specified TCP, then that TCP must be labeled as “planned”.

Figure 8 and the associated tables (7a and 7b) show one application of these conditions. In this example, the aircraft flies an 030 heading to intercept a lateral FMS path (TCP #1) consisting of waypoints ABC (TCP #2) and DEF (TCP #4). The aircraft also climbs at constant vertical speed and levels off at FL210 (TCP #3). Tables 7a and 7b show TCR’s for Figure 8 provided by a fully equipped aircraft (able to support all Rev. A elements) and one considered to represent an early (partially equipped) glass cockpit aircraft, respectfully. Both aircraft are flying with the autopilot or flight director engaged.

The fully equipped aircraft (Table 7a) provides FMS estimates for the latitude and longitude at the intercept point and MCP level-off. Altitude estimates are provided at waypoints ABC and DEF. Since heading legs are not supported in ARINC 702A, the track to path intercept must be updated with the current track. The aircraft will join the path with a fly-by turn.

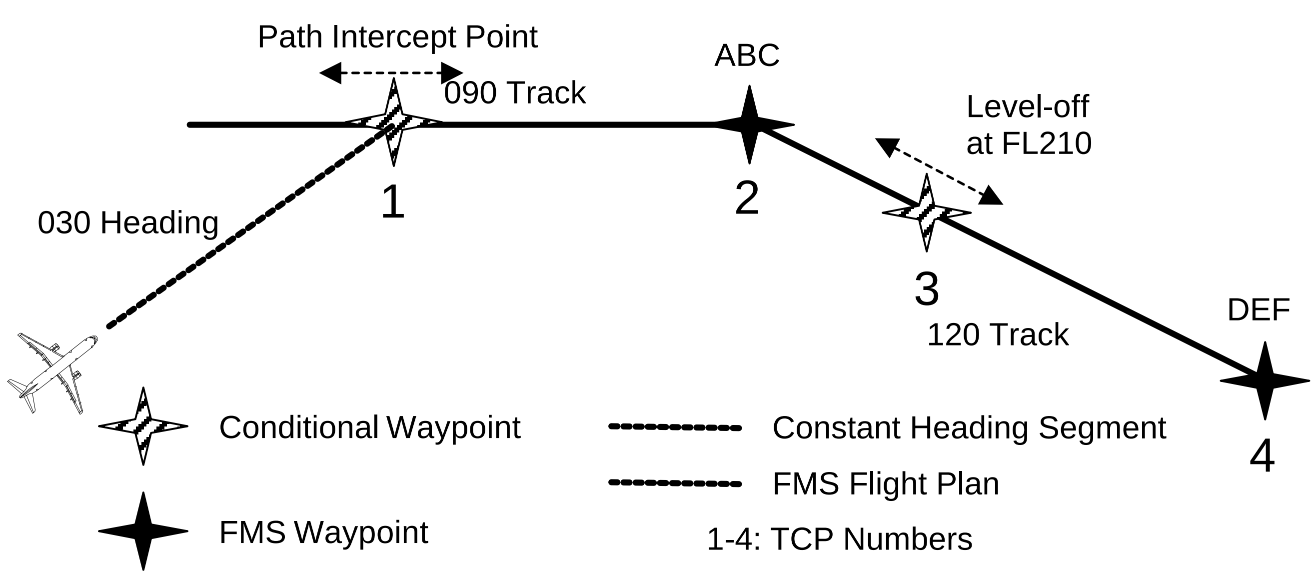


Figure 8: Constant Vertical Speed Climb and Constant Heading to Intercept FMS Flight Plan

Table 7a: Trajectory Change Report Elements for Figure 8 (Fully Equipped Aircraft)

#	Contents	TCR Values	TCR+1 Values	TCR+2 Values	TCR+3 Values
4	TCR sequence number	0	1	2	3
5	TCR Cycle number	0	0	0	0
6	Time to Go (TTG)	TTG-Intercept	TTG-ABC	TTG-MCP_ALT	TTG-DEF
7	Data Available (Horiz)	Available	Available	Available	Available
8	TCP Type (Horiz)	Fly-by	TF and Fly-by	Course to Fix	TF and Fly-by
9a	Latitude	Est	$Latitude_{ABC}$	Est	$Latitude_{DEF}$
9b	Longitude	Est	$Longitude_{ABC}$	Est	$Longitude_{DEF}$
10	Turn Radius	Intercept Radius	$Radius_{ABC}$	X	$Radius_{DEF}$
11	Track to TCP	Current Track	090	120	120
12	Track from TCP	090	120	X	Track from DEF
13	(Reserved - Horiz)	*	*	*	*
14	Command/Planned -H	Command	Command	Command	Command
15	Data Available (Vert)	Available	Available	Available	Available
16	TCP Type (Vertical)	Estimate	Estimate	Target Altitude	Target Altitude
17	Altitude	Est	Est	~~FL~~210	~~FL~~210
18	Altitude Type	MSL	Flight Level	Flight Level	Flight Level
19~~8~~	(Reserved)	*	*	*	*
20~~1~~ ~~9~~	(Reserved)	*	*	*	*
21~~0~~	(Reserved – Vert)	*	*	*	*
22~~1~~	Command/Planned -V	Command	Command	Command	Command

The partially equipped aircraft (Table 7b) has an MCP and FMS. The FMS cannot predict the location of the path intercept and does not provide lateral position ~~or time estimates~~ for the MCP level-off. Target altitude in this case represents the selected altitude provided by the TSR. Since the FMS does not support path intercepts, no TCR is provided for TCP #1 (a blank column is provided for clarity). For this reason, all horizontal TCP's are "planned". All vertical TCP's are "planned" because the aircraft cannot fully determine next target altitude. For instance, it has no means to determine if an intermediate level-off (such as an altitude constraint) will occur between the aircraft's current position and the MCP level-off at FL210. Note: TTG to MCP level-off can be estimated from estimated altitude at ABC, TTG to ABC, and climb rate, if no time estimate is given by an FMS avionics bus.

Table 7b: Trajectory Change Report Elements for Figure 8 (Partially Equipped Aircraft)

#	Contents	(No Report for Intercept Pt)	TCR Values	TCR+1 Values	TCR+2 Values
4	TCR sequence number		0	1	2
5	TCR Cycle number		0	0	0
6	Time to Go (TTG)		TTG-ABC	TTG-MCP_ALT	TTG-DEF
7	Data Available (Horiz)		Available	Not Available	Available
8	TCP Type (Horiz)		TF and Fly-by	X	TF and Fly-by
9a	Latitude		Latitude_{ABC}	X	Latitude_{DEF}
9b	Longitude		Longitude_{ABC}	X	Longitude_{DEF}
10	Turn Radius		Radius_{ABC}	X	Radius_{DEF}
11	Track to TCP		090	X	120
12	Track from TCP		120	X	Track from DEF
13	(Reserved - Horiz)		*	*	*
14	Command/Planned -H		Planned	X	Planned
15	Data Available (Vert)		Available	Available	Available
16	TCP Type (Vertical)		Estimate	Target Altitude	Target Altitude
17	Altitude		Est	210	210
18	Altitude Type		Flight Level	Flight Level	Flight Level
19	(Reserved)		*	*	*
20	(Reserved)		*	*	*
21	(Reserved – Vert)		*	*	*
22	Command/Planned -V		Planned	Planned	Planned

"Est": Element contents filled with FMS estimates, if available.

The TCR format provides a flexible structure for accommodating aircraft with widely varying navigation and automatic flight equipage. In addition to the partially equipped FMS aircraft represented in Figure 7b, numerous other variations are possible. For example, many RNAV and GPS systems only allow lateral waypoints and have no associated altitude estimate. Capability is also provisioned in the TCR for handling additional TCP types in future MASPS revisions. As discussed above, future DO-242 revisions may include the capability to report waypoint constraints. Altitude constraints are likely to benefit a number of applications and space is made available for these point types in Revision A.

9. Horizontal and Vertical TCP Types

A limited number of basic horizontal and vertical TCP types are accommodated in our proposal to enable representation of common trajectory flight segments for flight path prediction. It is expected that future revisions of the MASPS will accommodate additional TCP types, depending on evolution of airplane avionics and on application needs, e.g. additional lateral types such as hold patterns and additional vertical types such as waypoint altitude constraints. Some of the TCP types such as Direct-to-Fix transitions and Fly-by-Turns are needed to represent non-precision trajectories where the inertial path over the earth is not entirely predictable. Other TCP types such as Course-to-Fix, Track-to-Fix and Radius-to-Fix turns are needed to represent precision RNP flight legs. (In the future, intent integrity concepts may be introduced to monitor conformance to horizontal and vertical RNP bounds. This version of the MASPS simply uses precision and non-precision TCP types.) The vertical TCP types include maintain or level at a Target Altitude (which may also be represented in the TSR report), and traditional Top-of-Climb and Top-of- Descent TCP's. Estimated Altitudes are provided when transitioning towards a target altitude at a lateral TCP. Altitude Constraints are also provisioned as a future TCP type.

Horizontal TCP Types:

- **Geodesic Path (Straight Course) to Fix Lateral Transition**

The Geodesic Path to Fix transition includes both Course to Fix (CF) and Track to Fix (TF) leg types. The lateral path is defined by a course or track angle to a 2-dimensional waypoint that delimits the TCP endpoint. See Figure 8. This TCP type is typically followed by a routing change, i.e. a Direct to Fix (DF) transition or a Radius to Fix (RF) turn. The case where a CF or TF leg ends with a Fly-By Turn is a separate case since more parameters are needed to represent Fly-By turn cases. From the viewpoint of the transmitting aircraft, CF and TF leg types are somewhat different since the latter represents a transition between a "from" waypoint toward the "to" waypoint / TCP point. However, from the receiving system viewpoint there is no difference between a CF and a TF leg ending at a TCP, since the "from" waypoint is only implicitly represented by the Track to TCP. Thus, both cases are combined into a single TCP type. Time-to-Go to TCP is also required in order to properly sequence this and other flight segments.

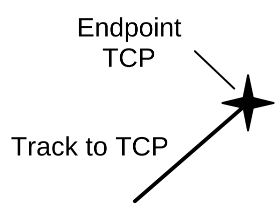


Figure 8: Geodesic Path to Fix Lateral Transition

- **Fly-By Turn Transition (Including CF or TF to Fly-By Turn segment)**

The Fly-By Turn TCR implicitly represents two flight segments, i.e. a straight segment such as a Course-to-Fix directed toward the Fly-By waypoint, and the actual Fly-By turn transition to the track-from course. Figure 9 shows the defining elements of a Fly-By turn, other than turn radius and turn center. Fly-By turns are considered non-precision leg types since the start-of-turn point and end-of-turn points constructed using turn radius are rough estimates of turn behavior, i.e. the actual path over earth can be substantially different due to winds and flight technical error. However, fly-by turns save message bandwidth compared to use of explicit TCP's for start and end of turn segment. Required elements include the fly-by latitude, longitude and time-to-TCP (time to Fly-By point sequencing), and track-to TCP, turn radius, and track-from TCP. Turn direction (one bit indicator) is also available for some systems and may be desirable for ADS-B transmission, but is not required for path reconstruction. Since end-of-turn is implicit, the TCR is sequenced when the track angle state captures the track-from TCP.

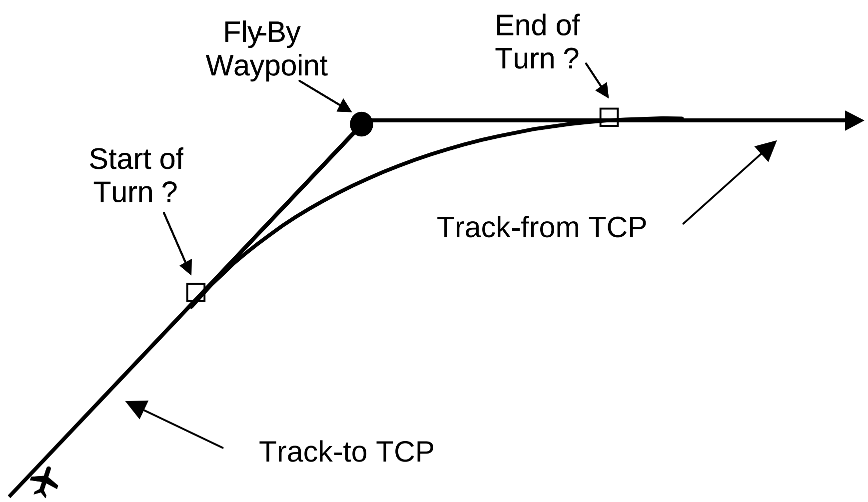


Figure 9: Fly-By Turn Transition with Turn Start and Turn Endpoints shown

- **Direct-to Fix Lateral Transition**

The Direct to Fix (DF) transition is defined implicitly as a path from the current horizontal position and velocity to the specified endpoint TCP. The transition typically consists of an initial turn transition to orient the velocity vector in the direction of the endpoint TCP, and a straight line segment proceeding directly toward the specified endpoint. See Figure 10. The Direct-to Fix can be used as a means of specifying a fly-over turn toward the next waypoint, and is considered a non-precision trajectory type since DF segments are typically not repeatable or well defined in terms of turn behavior. Mandatory elements for the Direct-to-Fix TCR include the endpoint latitude, longitude and estimated time-to TCP, and a track-to TCP which can be computed from the latest reported position state vector as the direction from the aircraft position to the TCP (assuming that DF is the active flight segment). The track-to TCP will change dynamically in the turn transition phase until the aircraft velocity vector is aligned toward the endpoint TCP, and then remains relatively constant after the turn segment is completed. (Note: the DF transition is backwards compatible with the original DO-242 TCP's.)

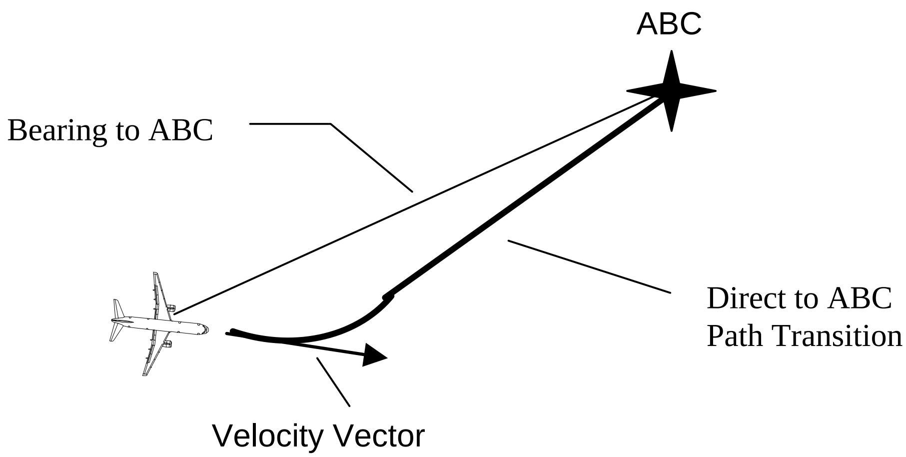


Figure 10: Direct to ABC Lateral Transition Example

- **Direct to Fly-By Turn Transition**

The Direct-to Fly-By is a combination of a Direct-to segment followed by a Fly-By turn. The information conveyed is very similar to the Fly-By turn transition, except for the meaning of the track-to Fly-By component, i.e. latitude, longitude, and TTG to the Fly-By waypoint are required as well as track-to, track-from and turn radius components. If the DF to Fly-By is the active flight segment, then track-to may be computed as the inertial track angle from the current aircraft position to the Fly-By waypoint. If the DF to Fly-By is preceded by an earlier TCP, then the track-to is computed as the track angle from the preceding TCP to the Fly-By waypoint. However, the trajectory reconstruction process is inherently different for a DF to Fly-By compared to a TF to Fly-By transition, since the DF transition typically includes a turn segment to align the velocity vector toward the Fly-By TCP, whereas the TF to Fly-By assumes a straight line trajectory from the previous waypoint or TCP. Figure 11 shows a DF to Fly-By transition.

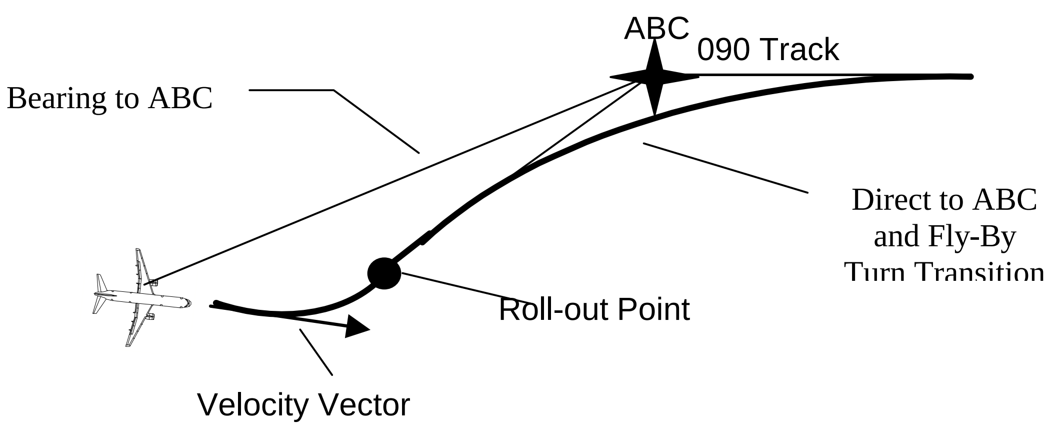


Figure 11: Direct to Fly-By Lateral Turn Transition

- **Radius to Fix Turn Transition**

The radius to fix (RF) turn transition describes a constant radial turn over the earth, beginning at a turn start point that is the previous TCP and ending at the endpoint fix. Typically RF turns are used to describe precision trajectories consisting of CF or TF to fix geodesic path segments and RF turn segments. Mandatory elements include the endpoint TCP latitude, longitude and time-to-TCP, the turn radius, and the track-from TCP. Turn direction can be transmitted also, but is not a required element. The turn center-point is constructed by first generating a line perpendicular to the track-from direction at the fix endpoint. The turn center-point is placed along this line segment at a distance equal to the turn radius from the endpoint fix. Care must be taken to achieve continuity of position and velocity when transitioning from the previous TCP to an RF turn segment. RF turns are considered a basic navigation leg type for implementing precision RNP routings. Figure 6 shows a geodesic path to fix entry and RF turn.

Vertical TCP Types:

- **Unknown Altitude Type**

This type is to preserve backwards compatibility with the original MASPS, i.e. a 3-D TCP is specified where the altitude value is an FMS estimate and may or may not represent one of the specified vertical TCP types below.

- **Target Altitude**

The vertical TCP types are either specific vertical transition types such as Top-of-Climb and Top-of-Descent with 3-D endpoints specified, or are simply level-off targets that end a vertical transition or denote the current maintaining altitude. Target altitude can be either an autopilot selected or an FMS target value such as selected cruise altitude. It is considered a TCP and separately reported and sequenced with other TCP's if the command trajectory has a climb or descent transition that ends by leveling off at the target altitude. A target altitude TCP can be different than the target altitude in the TSR report. For example, if the aircraft is maintaining cruise altitude prior to Top-of-Descent and the MCP Selected altitude is set to an intermediate altitude, then the active target altitude is the selected cruise altitude, and the next two vertical TCP's are the Top-of-Descent point and the MCP selected altitude. (See Figure 5.) The only required TCP element for this type is the target altitude, although latitude~~,~~ and longitude ~~and time-to-TCP~~ are desirable whenever available. ~~If no time-to-TCP is specified, then the order of TCP's is determined by altitude precedence, i.e. in the above example Top-of-Descent would be the current TCP and target altitude would be TCP+1.~~

- **Top of Climb (TOC)**

Top of Climb is the TCP endpoint of the climb phase of flight, i.e. Top-of-Climb designates the point where the aircraft levels off at a desired cruise altitude. Top-of-Climb is specified by latitude, longitude, and time-to-TCP estimates, as well as the selected cruise altitude. Note, after a TOC TCR, the next TCR contains a vertical TCP with either a Target Altitude (which can be the current cruise altitude or an intended step change altitude) or the Top-of-Descent (see below).

- **Top of Descent (TOD)**

Top of Descent is the planned endpoint of the cruise phase of flight, i.e. Top-of-Descent designates the point where the aircraft is scheduled to begin descent from cruise altitude. Top-of-Descent is specified by latitude, longitude, and time-to-TCP estimates, as well as the selected cruise altitude. The next TCR after a TOD should contain a Target Altitude or End-of-Descent vertical TCP with altitude value less than the cruise altitude at TOD. (Note: ideally all points where a vertical transition from level flight begins should be delimited as TCP's also, e.g. start-of-climb from an intermediate flight level. However, the pilot may simply use the autopilot interface with a new selected altitude and manual engagement to start such flight segments, or alternately may use an "At" constraint at a waypoint with FMS engagement of the next vertical transition segment to achieve the same purpose. In the latter case, the level segment ends when the "At" constraint is sequenced.)

- **Estimated Altitude**

If the aircraft is in climb or descent mode transitioning towards the next level-off altitude when a lateral waypoint or TCP is sequenced, the altitude value is typically estimated by the FMS, i.e. if the aircraft is not maintaining a target altitude or subject to an altitude constraint at the waypoint, then the altitude value provided by the FMS is an estimated altitude.

- **Altitude Constraints (At, At and Above, At and Below)**

Altitude constraints are often used in the climb and descent phase of flight to maintain separation of departure, arrival, and over-flight traffic patterns in congested airspace. Altitude constraints are provisioned in Revision A since current FMS buses do not provide such information to external data users. Representation of altitude constraints is considered essential for future versions of this MASPS (after Rev A) since vertical path intent is not complete until such intent data is available. Moreover, altitude constraints are the basis for implementing vertical RNP using altitude "window" constraints in future RNP systems (Ref. 5). Altitude constraint TCP's will require specification of waypoint latitude and longitude, and time-to TCP, the actual altitude constraint value, and the type of constraint, i.e. At, At and Above, or At and Below. The exact TCR representation of such constraints is currently under consideration, i.e. how to accommodate window constraints consisting of a simultaneous At and Below and an At and Above constraint at the constraint fix. Three bits are provisioned in Revision A to accommodate future expansion.

10. **Minimum Intent Report Requirements**

<u>Equipage Class Requirements</u>

In the current MASPS, Level A0 and Level A1 equipage provides basic state vector broadcast capability for VFR and IFR users, respectively. In the current MASPS, Level A2 equipage was defined to support extended range ADS-B applications to 40 nm range and provides at least a single TCP broadcast in order to assure the validity of trajectory predictions for several minutes look ahead. Level A3 equipage was similarly defined to support extended range applications such as flight path de-confliction out to 90 nm range and provides at least two TCP broadcasts to assure continuity of trajectory predictions near the first TCP, and to achieve at least five minutes trajectory look ahead time.

Our proposal for Revision A equipage classes is to retain the concept and overall capability of Level A2 and Level A3 equipage, but to revise the definitions to better reflect horizontal and vertical autopilot and RNAV capability. A minimum Level A2 ADS-B system would have the ability to broadcast target altitude and target heading, and at least one TCR report. The reason for requiring target altitude is to assure that a Level A2 system has some intent capability in both horizontal and vertical axes, i.e. to support extended range predictions in both horizontal and vertical dimensions. A minimum Level A3 ADS-B system would have Level A2 capability and the capability to broadcast at least four TCR reports. The reason for requiring four TCR reports as compared with two TCP's in the current MASPS is that there are several conditions where two TCP's is not sufficient to predict ahead five minutes or to 90 nm range. Specifically, routing changes are quite frequent in the terminal area transitioning towards final approach or on initial departure after take-off. Under these conditions additional TCP's are needed to achieve desired look ahead time for terminal area planning applications. Other potential applications that could require more TCP's include air-ground planning applications for en-route traffic flow management, and transition between free flight air-air operations and ATC managed traffic.

Transmission Update Requirements

Current requirements on update rate for TCP's are partly implicit and are not directly related to the functional requirements for applications, i.e. "The rate shall be sufficient to ensure continuous positive assessment by the receiving aircraft at least 2 minutes prior to reaching the closest point of approach for class A2 equipage (5 minutes… for class A3)". In addition, TCP update rates as a function of range are specified in Table 3-4 as equal to the coast interval for state vector reports, with 95% confidence of reception. ~~Moreover~~In addition, most TCP intent data is static or slowly changing until the time to TCP is imminent or the TCP point is sequenced. It was concluded after review of the current MASPS, that more direct requirements on required update rate are needed for TSR and TCR reports, and TCR data should be updated less frequently for TCP's that have large TTG values.

The proposed update requirements would broadcast TCR reports at a high rate when TTG to TCP is less than a threshold value, i.e. when less than 2.5 minutes TTG, and at a much lower rate when TTG to TCP is larger than the threshold value. TSR reports would also be broadcast at the higher rate. (The 2.5 minute threshold is based on a nominal time budget for a flight plan deconfliction application where sufficient look ahead time is needed to detect and resolve a predicted air-air conflict.) In addition, major changes in TSR or TCR intent (to be signaled in the Mode Status report) may require prompt updating of all affected intent reports.~~TCR's.~~

The update requirements for TSR's and TCR's are specified, as in the current MASPS, as a function of range and in terms of the update interval TU for 95% reception probability of a single

TSR or TCR report. Table 8 summarizes the proposed requirements for update interval as a function of range and report update condition, i.e. the triggering condition for broadcasting report updates. There are three different priorities for TSR and TCR updates:

- Highest priority for report updates (smallest TU interval) is after a major change of intent or a newly initiated broadcast of TSR or TCR data.
- Second highest priority for report updates is for nominal TSR or TCR updates following a major change of intent, and with TTG <= 150 seconds (2.5 minutes).
- Lowest priority (largest TU interval) is for nominal TCR updates with TTG > 150 seconds and less than 300 seconds.

There is no explicit requirement for broadcast of TCR's with TTG exceeding 5 minutes, i.e. ~~The high rate update requirement is for the broadcast rate to be sufficient to achieve a 95% reception probability of a TCR or TSR report within a 10 second period. (This requirement is consistent with the current MASPS requirement that "… the report assembly function shall provide update when received or indicate "no data available" if none is received in the preceding 10 second period", i.e. the high rate coast time for TSR and TCR reports is 10 seconds.) The low rate broadcast requirement is to receive at least one broadcast TCR report with 99% reception probability between 5 minutes TTG and 2.5 minutes TTG to TCP. (For example, this requirement may be achieved with a low rate broadcast of 30 seconds per transmission and a reception probability of at least 70% per broadcast.) T~~the proposed rate requirements emphasize the importance of TCR information within 2.5 minutes TTG and de-emphasize the relative value of remote TCR information with TTG greater than 5 minutes.

Table 8: Proposed ADS-B Update Requirements for Intent Reporting (Note 5)
(Minimum 95% Update interval requirements in seconds)

Report Type	**R<= 20 nmi**	**R<= 40 nmi**	**R<= 60 nmi**	**R<= 90 nmi**	**R<= 120 nmi**	**Notes**
	A2 req'd	A2 req'd	A3 req'd	A3 req'd	A3 desired	(1)
TSR state change	12	12	13.2	19.8	26.4	(2)
TCR state change	12	12	13.2	19.8	26.4	(2)
TSR - nominal	12	18	27	40.5	54	(3)
TCR – nominal With TTG<= 150	12	18	27	40.5	54	(3)
TCR – nominal With TTG > 150 s	18	26.4	39.6	59.4	79.2	(4)

Notes: (1) For a Level A2 system, 40 nm reception in the forward direction is required, 50 nm is desired.

(2) Formula for TU update is TU = max(12, 0.22*R). This formula is about half that for nominal TSR and TCR updates to assure prompt updating of intent after a major state change.

(3) Formula for nominal TU update is TU = max(12, 0.45*R). This formula allows for up to a 15% loss in range to update intent reports, with 95% confidence.

(4) Formula for nominal TCR update with 150<TTG<=300 sec is TU = max(18, 0.66*R). This formula allows substantially larger update intervals when TTG exceeds 150 seconds.

(5) Table 8 is based on an air-air enroute scenario between two aircraft closing at 1200 knots, which is considered a worst case for deriving range requirements for ADS-B conflict alerting.

In addition to the above rate requirements, Revision A would limit the conditions when a TCR report needs to be broadcast. A TCR report for any TCP other than the active TCP would not be required if TTG to that TCP exceeds TBD minutes. (Suggested TBD value = 20 minutes). For example, if TTG to the next trajectory waypoint is 26 minutes, then no TCR reports beyond the next waypoint (TCP+0) are required. This limitation would prevent indiscriminate broadcast of TCR reports that are not operationally relevant.

TCR Report Synchronization and TTG Refresh

It is assumed that most ADS-B systems will require multiple messages to construct a complete TCR report sequence when broadcasting multiple TCP's. It then becomes necessary to ascertain that whenever a TCP is sequenced or intent information is changed, that the TCR's are appropriately synchronized and that all TCR's reported are currently valid and have the correct TCR sequence number. In order to achieve proper synchronization, all broadcast messages related to TCR intent need to contain some mechanism for validating TCR messages that originated together as a coherent group of sequenced TCP data, and for rejecting old TCR data that originated prior to the latest change in intent information.

One means of achieving TCR report synchronization is to report a two bit (or larger) TCR cycle number for all TCR related messages, including Mode Status reports of a change in TCP data. All TCR reports which are output at a common time of applicability would be checked to assure that the cycle number for the underlying messages was current and common to all TCR reports, i.e. any intent data which contains an old cycle number would be purged and not reported with current TCR data. In the case where the change consists of a sequencing (passing through) the TCP+0 point, a TCP+0 sequencing flag in the Mode Status report is used to flag that the data in TCR+1, TCR+2, and TCR+3 can be reused by decrementing the TCR sequence number and updating the common time of applicability, i.e. TCR+1 becomes TCR+0, etc. The TCR cycle number is also updated in this case, so that the resequencing process is not repeated at a later update time, until a new TCR cycle number is reported.

The TCR cycle number would be incremented each time a major change in intent is detected by the ADS-B transmitting subsystem, i.e. the TCR cycle number would cycle from 0 to 1 to 2 to 3 to 0 again as the transmitted intent sequence or intent data is changed. (Simple changes in estimated values such as estimated altitude at a waypoint are not considered major changes in intent, nor would addition of a TCR report with sequence number higher than those currently being reported. Major changes of intent typically would result in TCR report resequencing or would involve changes in TCP type associated with a pilot input, e.g. a "direct to" clearance that bypasses one or more current TCP points.) The message synchronization process must assure that only currently valid TCR data is being reported and that each TCR report at a common report time has a unique sequence number.

TTG is originally computed from ETA or estimated time of arrival at a waypoint as the time difference between the ETA point and the estimated time of applicability for ADS-B broadcasting. When TCP message data with TTG is received, coast time is set to zero, and TTG is referenced relative to the report Time of Applicability. If no further messages for that TCP are received at the next report time, then coast time is incremented and TTG is decremented by delta time of applicability, i.e. the report time, coast time and TTG are all updated relative to the current time of applicability. This process of TCR 'refreshment' continues until an updated TCP message with TTG is received, or the coast time exceeds a threshold limit for data renewal and the TCR data is marked "not available", or the TCP change point is sequenced.

11. References

(1) Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B), RTCA DO-242, Washington D.C., 1998.

(2) "Automatic Dependent Surveillance Requirements," Eurocontrol SUR/ET3/STO6.3220/001, June 2001.

(3) ARINC Characteristic 702A-1, "Advanced Flight Management Computer System", Jan. 2000.

(4) Barber, S. and Ponnau, M., "Review of Register 4,0," Surveillance and Conflict Resolution Systems Panel (SCRSP) Surveillance Systems WG/B, Rio de Janeiro, Apr. 2001.

(5) Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, RTCA Document DO-236A, SC-181, Sept. 2000.

12. Glossary of Trajectory / Intent Terms

Active Trajectory - The *active* trajectory or flight segment refers to the current path and automation states being used for guidance and control of the aircraft.

Command Trajectory - The *command* trajectory refers to the path an aircraft will fly if the pilot does not engage a new flight mode nor change parameters for the active or upcoming flight segments.

Non-Precision Trajectory – A *non-precision* trajectory refers to an aircraft path with no specific containment bounds between the intended path or flight parameters and the actual path flown. Typically, transitions to an intended trajectory such as Direct To segments are non-precision, whereas aircraft flying RNP path segments with known lateral and vertical containment are precision trajectories. (A trajectory can also be a precision flight path in the horizontal and non-precision in the vertical plane.)

Planned Trajectory - The *planned* trajectory includes intent information that is conditional upon the pilot engaging a new flight mode. Without pilot input, the aircraft will only fly toward the command trajectory. If the aircraft system is unable to determine whether a trajectory segment is planned or command, then the default type is a planned trajectory.

Selected Altitude – *Selected Altitude* is an altitude value which is dialed in an autopilot interface such as a Mode Control Panel to specify a desired limit value for climb or descent segments, or to specify a desired target altitude to maintain for level flight segments.

Selected Heading / Track – *Selected Heading* is a desired air reference heading value which is dialed in an autopilot interface such as a Mode Control Panel to specify a target value to transition towards and maintain for constant heading angle flight. *Selected Track* is similar to selected heading except that the directional reference is inertial track angle rather than heading.

Short Term Intent – *Short Term (TSR) Intent* refers to the intended path and intended flight parameters on the currently active flight segment. Short term intent can refer to either autopilot or FMS/ RNAV parameters associated with the current flight segment.

Target Altitude – Ideally, *target altitude* is the aircraft's intended level-off altitude if in a climb or descent, or the aircraft's current intended altitude if it is being commanded to hold altitude. However, since many aircraft only have limited ability to communicate target altitude, it is acceptable to broadcast alternatives to target altitude based on aircraft capability. See Appendix C for specification details.

Target Heading / Track – *Target Heading / Track* is the heading or track angle target used by the aircraft guidance system to acquire or maintain the lateral path. The actual value used depends on the active guidance source, i.e. allowed values include Selected Heading / Track for direct autopilot specification, Heading/ Track Hold for autopilot maintenance of the current heading or track angle, and FMS / RNAV specified track angle to the next lateral waypoint.

Time of Applicability – *Time of Applicability* is defined in the DO-242 MASPS as the time of report validity. Since Time to Go (TTG) is defined as the "estimated remaining flight time to the TCP point", we here interpret time of applicability for TCR reports as the current time for newly received report data. TTG then represents time to TCP relative to current time of applicability.

Trajectory Change Point - A *Trajectory Change Point* may be described as a 3D location or interception of a 2D plane with the aircraft's velocity vector where the current aircraft trajectory is intended to change. See Appendix B for example TCP's.

Appendix A: Future Plans for Intent Consideration

TSR and TCR Report Format Validation

Although considerable effort was expended in developing and evolving the TSR and TCR report formats for ADS-B intent broadcast during 2000 and 2001, this work did not include simulation or detailed analysis of proposed ADS-B intent formats. Future simulation and flight test studies of proposed operational concepts using intent broadcast are needed to validate the formats and intent structure developed for Revision A, and to further evolve ADS-B intent standards for future Revisions of the ADS-B MASPS. This work needs to be coordinated with the operational groups developing intent based operational concepts, in order to further mature the use of airborne intent for surveillance and separation assurance applications.

Intended Airspeed Reporting

Revision A of the MASPS limits intent reporting to horizontal and vertical target states and trajectory change points. Other types of intent such as target airspeed and target vertical rate were not considered for TSR reporting in Revision A since there seems to be less agreement as to the importance and operational utility of such data. There are some applications such as in-trail approach monitoring where intended airspeed may be extremely valuable, e.g. to cue the trailing aircraft that the lead aircraft is decelerating to a target airspeed value. Similarly, several recent studies have shown the value of reporting aircraft minimum approach speed (VREF), to properly space aircraft on final approach prior to deceleration to landing speed. Airspeed changes were not included in the proposed TCR reports, since gross changes in airspeed are accommodated by including Time-to-TCP as a report element. However, potentially important variables such as intended airspeed and the potential use of airspeed TCP's will be reexamined in future MASPS.

Additional TCP Leg Transition Types

The TCP leg types that were considered for Revision A were limited to basic leg types for horizontal and vertical transitions. There are other leg types that are potentially available from FMS systems, e.g. procedure holds, Mach /CAS cross-over speeds on climb and descent, planned changes in vertical rate or flight path angle, longitudinal deceleration prior to meter fix entry, etc. Expansion of TCP leg types will be reexamined for future MASPS use based on operational value and future development of separation assurance operational concepts.

RNP based Intent Integrity Monitoring

The extent to which intent data can be used for critical separation assurance applications will depend on the integrity of such data, i.e. the reliability of trajectory path following and staying within specified bounds of the intended path. The RNP RNAV MASPS (Ref. 5) specify integrity containment bounds for path following which can serve as a basis for intent integrity metrics for ADS-B reporting, provided such aircraft are RNP qualified. In the future MASPS it is expected that RNP metrics and altitude "windows" may be used to express aircraft capability to stay close to the broadcast path, and to fly within specified trajectory "tubes". This version of the MASPS did not include RNP integrity metrics since operational concepts for trajectory based separation assurance are not considered sufficiently mature, and only limited operational experience is available to assess the value of RNP systems. The material below summarizes the overall concept of RNP containment integrity and conformance monitoring.

In the horizontal plane, RNP accuracy and integrity bounds are used to describe the expected lateral path deviation and the allowable lateral path deviation for path conformance. An RNP-1 RNAV system, for example, is certified to stay within 1 nm of the intended lateral routing at least 95 % of the time, including turn maneuver periods. The RNP integrity bound for conformance monitoring is twice the accuracy value, i.e. a conformance warning is generated by the RNAV system if the aircraft deviates from the intended lateral path by more than 2 nm. If TCR intent data is to be used for critical separation assurance applications, such as detecting and resolving flight path conflicts, then it may be necessary to expand TCR data to incorporate lateral RNP RNAV capability and a lateral RNP conformance flag (element 12 of Table 4) for assessing the integrity of horizontal TCR data. The transmitted conformance flag would indicate that the aircraft was capable of detecting a loss of RNP containment, and that the current lateral path deviation was within allowable limits for lateral path conformance. Since the broadcasted intent data could potentially result in misleading predictions of the future intended aircraft path, conformance monitoring on the ADS-B receive side may be necessary as well. Figure A-1 illustrates the concept for user conformance monitoring of lateral path predictions for a horizontal turn maneuver. In this example, the aircraft is moving along an intended path toward the left side TCP start of turn point to the right side TCP End-of-Turn TCP point. As the aircraft approaches the RNP route bound, a conformance alert is generated, cautioning the data user of a potential integrity error in the broadcast path. When the aircraft flies outside the intended RNP containment region a conformance warning is generated, indicating an intent integrity error.

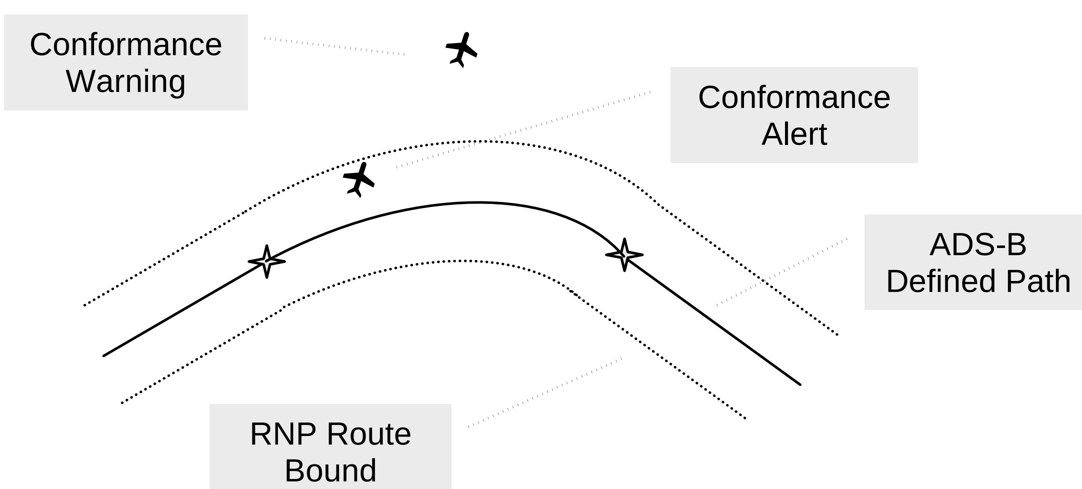


Figure A-1: RNP Lateral Conformance Monitoring For Intent Validation

In the vertical plane, RNP integrity is specified as the allowable vertical containment at specified waypoints (Ref. 5), using either "window" altitude constraints or an "At" constraint at each vertical TCP. This is shown for a descent example in Figure A-2. The airplane would be expected to stay within the vertical bounds better than 99% of the time (using thrust or drag energy management if necessary), and to broadcast an alert message if unable to comply with the specified vertical tolerances. The vertical RNP concept is more restrictive than existing altitude constraints and will need operational validation before implementing in future ADS-B MASPS. It is expected that two quantities would need to be added to TCR reports for implementation, i.e. the delta height between upper and lower constraints, and a vertical conformance flag (element 19 of the TCR report).

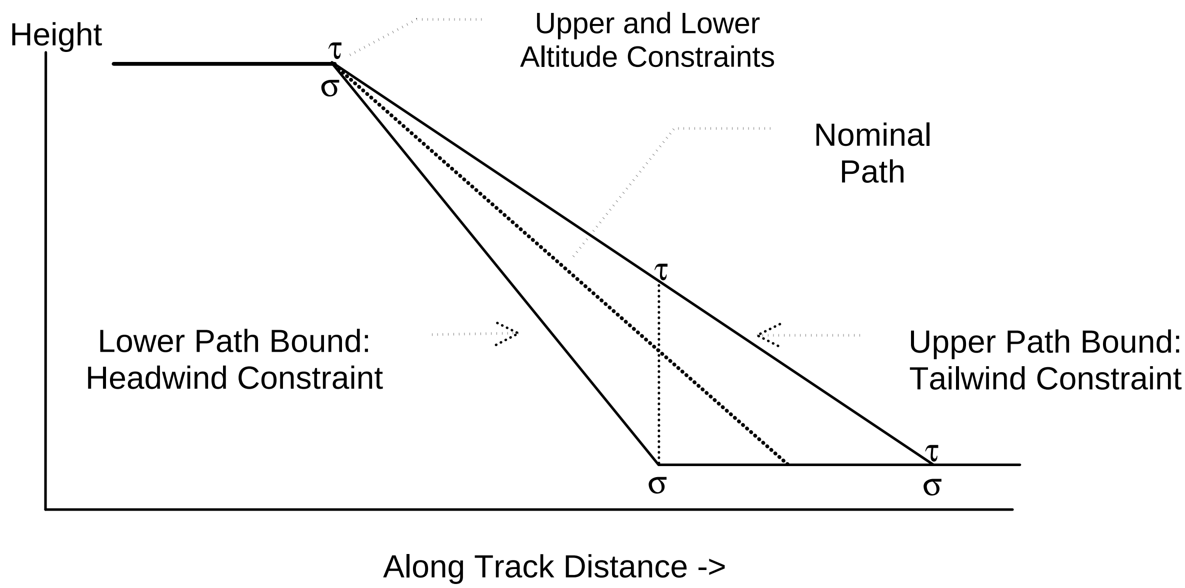


Figure A-2: Vertical Path Conformance Region for Descent Example

Appendix B: Trajectory Change Point Description and Examples

A Trajectory Change Point may be described as a 3D location or interception of a 2D plane with the aircraft's velocity vector where the current aircraft trajectory is intended to change. In the latter case, the aircraft is not controlled to a known 3D location. Instead, the Trajectory Change Report (TCR) defines a set of conditions, that when satisfied, cause the transmitting aircraft to recognize that it has reached the TCP. Some aircraft may be able to estimate non-controlling TCP dimensions (latitude/longitude, or altitude, depending on the TCP type). As discussed in Section 6, unknown wind conditions or aircraft performance may limit the accuracy of these predictions. Nevertheless, they may be used to fill the TCR, if available. Not all examples presented in this Appendix are supported in Revision A. However, the TCP definition is sufficiently general to allow support of these TCP types in the future.

Figures B-1 through B-4 illustrate several ways in which TCP's might be described in TCR's. In Figure B-1, the TCR specifies the TCP's latitude, longitude, and altitude, thereby defining the TCP as a specific point in three-dimensional space. An example of this kind of point would be an FMS waypoint with a mandatory altitude. The altitude could occur in the form of a waypoint crossing restriction or an assigned altitude. TCP #4 in Figure 8 is an example of the latter case. The aircraft has reached the FL210 assigned altitude and is flying to the DEF waypoint.

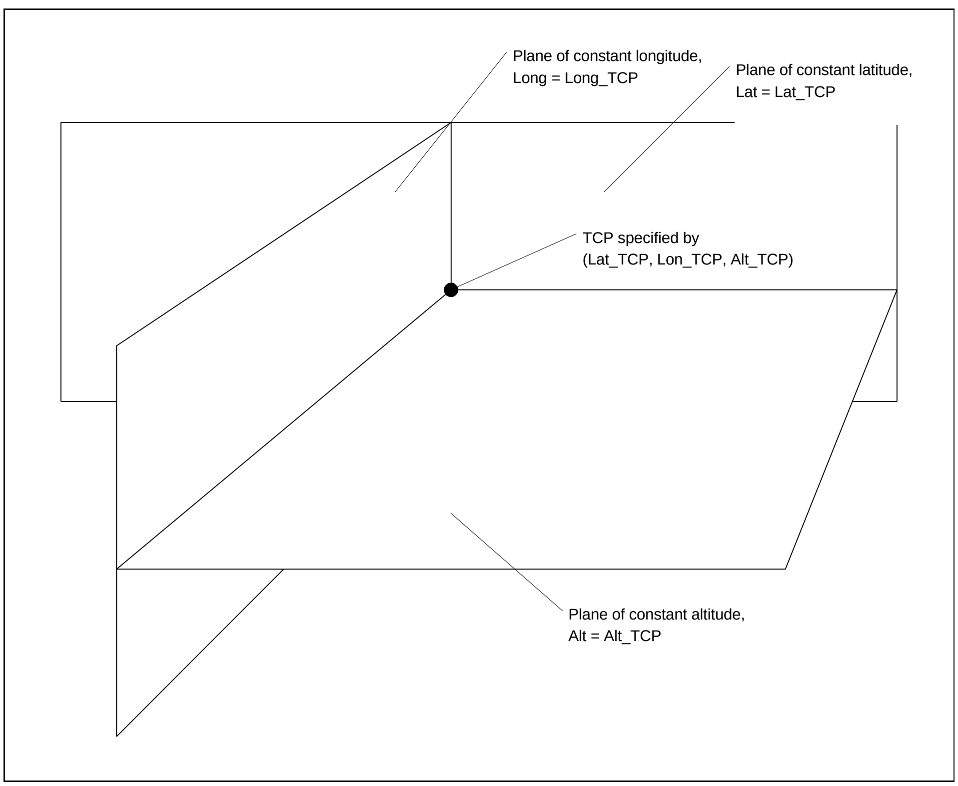


Figure B-1: TCP Defined by Latitude, Longitude, and Altitude

In Figure B-2, the TCP's latitude and longitude are known, but its altitude is left unspecified. The TCR that describes this TCP will include values for the parameters Lat_TCP and Lon_TCP, but not for Alt_TCP. Equipment on board the transmitting aircraft will know that it has reached the TCP when the own-ship latitude and longitude are sufficiently close to the specified Lat_TCP and Lon_TCP values. TCP #2 in Figure 8 is an example of this type of point. The aircraft is not required to cross ABC at a particular altitude. TCP #2 is sequenced when reaching the lateral position defined by waypoint ABC.

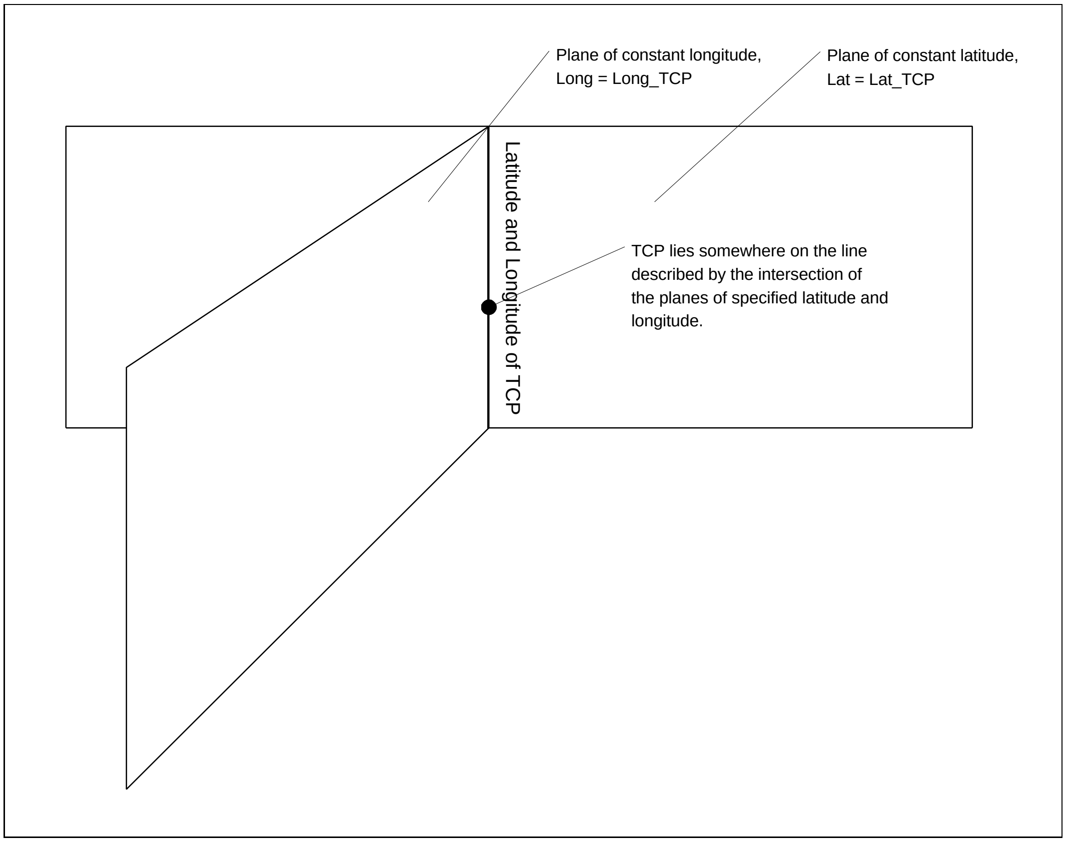


Figure B-2: TCP Defined by Latitude and Longitude.

Another way that a TCP might be described in a TCR is as the intersection of the aircraft's velocity vector (as defined in the SV report) with a plane that defines a specified course to a downstream TCP (see Figure B-3). When reaching this kind of point, the aircraft will turn to fly the specified course to a CF (course to fix) TCP. Altitude is not a constraint for this type of TCP. TCP #1 in Figure 8 is an example of this TCP type. In the example, the aircraft is flying a 030 heading to intercept the 090 course to the ABC waypoint. Due to wind conditions, the TCP may drift left or right along the course to ABC.

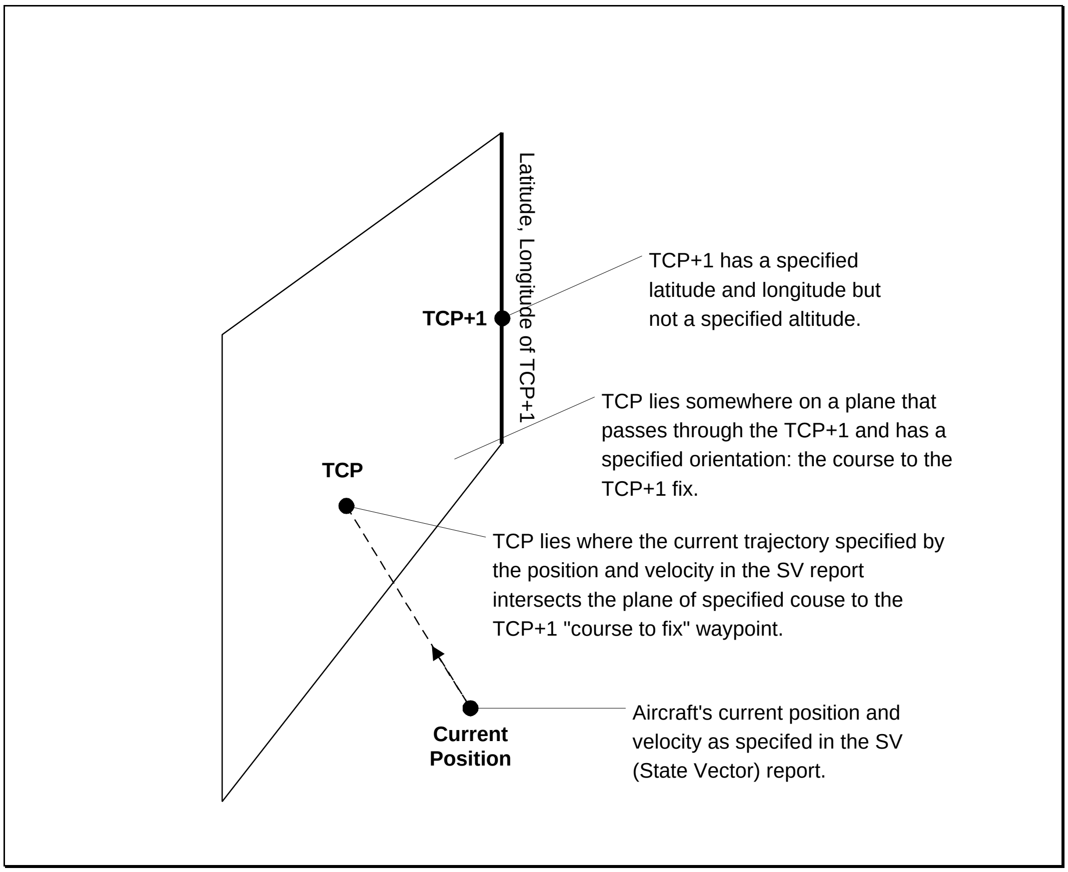


Figure B-3: TCP Defined by SV and Course to Fix Waypoint

A TCR may also be the intersection of the aircraft's velocity vector with a known altitude. This kind of point would be used to specify reaching a target altitude, such as the climb shown in Figure 3. Figure B-4 illustrates this TCP type.

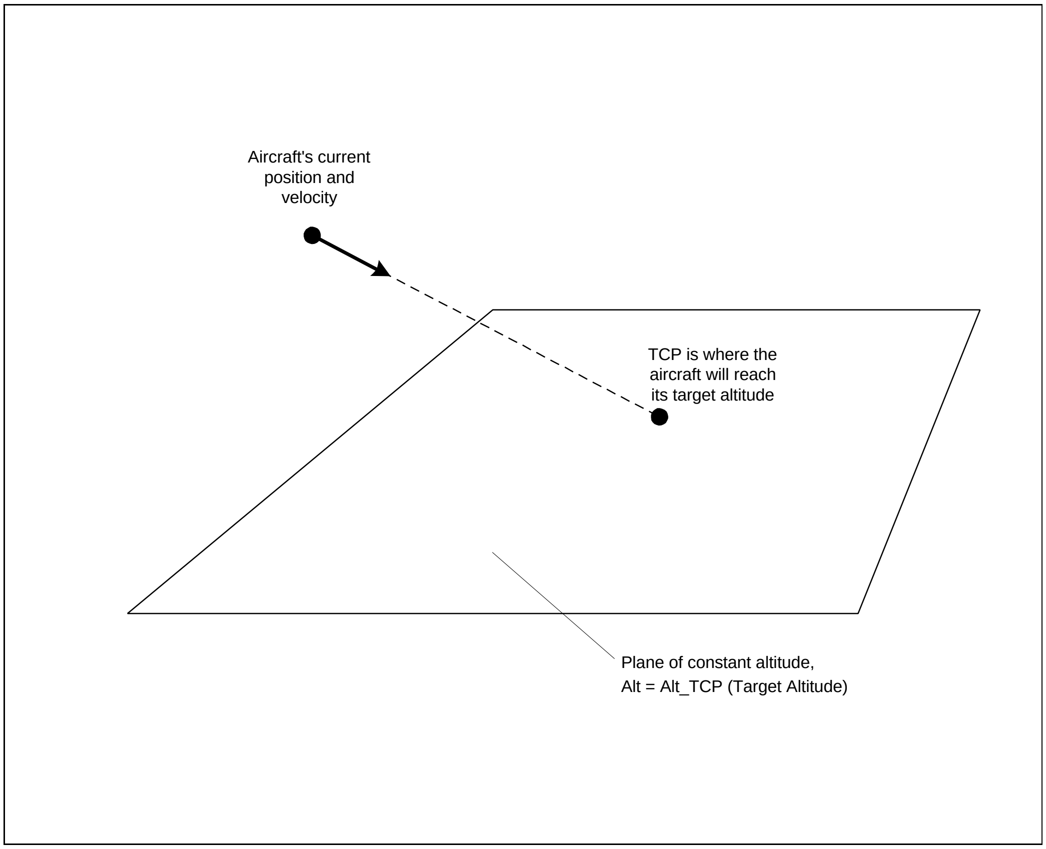


Figure B-4: TCP Defined by Target Altitude

Appendix C: TSR and TCR Element Descriptions

TSR State Report Elements

In this section we describe each of the report elements directly associated with target altitude and target heading / track and typical data sources for creating such report elements. There are four data elements associated with target altitude and four data elements associated with target heading / track which are used to interpret the meaning of the target states being reported. See Table C-1, below.

Table C-1: Target State Report Elements

Element #	Contents
5	Target Altitude
6	Target Altitude Type
7~~6~~	Target Altitude Capability
8~~7~~	Target Source Indicator (Vertical)
9~~8~~	Mode Indicator (Vertical)
11	Target Heading / Track
12	Heading / Track Indicator
13	Target Source Indicator (Horizontal)
14	Mode Indicator (Horizontal)

Target Altitude (element 5) can potentially come from three different sources aboard the transmitting aircraft, depending on the vertical Target Source Indicator (element 8~~7~~), i.e. *Target Source Indicator* is defined by the following values:

0 = Selected Altitude from the autopilot interface
1 = Holding Altitude from the vertical guidance function (or current altitude as an alternative)
2 = FMS target altitude from a Flight Management interface or output bus.

Target Altitude Type (element 6) indicates whether the target altitude is referenced to mean sea level (MSL) or to flight level (FL). This is determined prior to ADS-B transmission based on whether the target altitude is below the local transition altitude or not.

The ADS-B MASPS supports 3 levels of *Target Altitude Capability* (element 7~~6~~) that delimits the data sources available for broadcast on the transmitting aircraft:

0 = Holding altitude or autopilot selected altitude.
1 = Holding altitude, autopilot selected altitude, or FMS cruise altitude.
2 = Holding altitude, autopilot selected altitude, or any FMS level-off altitude.

Target Altitude Capability is specified when installing and configuring the ADS-B transmitting system. It is recommended that implementers defer full target altitude capability (value = 2) until a later MASPS version, so that certain data source issues and data architecture issues can be resolved with appropriate data standards. The data sources and translation logic to provide data elements 5~~4~~ to 8~~7~~ for capability levels 0 and 1 are much easier to implement with current avionics systems, and are consistent with vertical TCP capability for Revision A.

The *Vertical Mode Indicator* (element 9~~8~~) signals whether target altitude is being acquired (i.e. a climb or descent toward the target altitude is in progress), or whether the target altitude has been captured or is currently being maintained. The values of the Vertical Mode Indicator are:

0 = Acquisition of target altitude (vertical transition in progress)
1 = Capture/Holding of target altitude.

Typically, in a digital airplane the status of the autopilot function and the horizontal and vertical flight management modes are displayed to the pilot via *Flight Mode Annunciators (FMA)*. The FMA are coded symbols summarizing the flight mode states that are currently active. For example, in a Boeing 737 digital airplane, if the FMS vertical navigation function is engaged then VNAV is displayed as one of the flight mode annunciators. The displayed mode annunciators can be used as a basis for setting the Target Source Indicator and Vertical Mode Indicator values, and for then selecting an appropriate target altitude. For example, if the aircraft is capturing or maintaining an autopilot specified level-off altitude in a digital 737 airplane, then the VNAV mode displayed is ALT. If an altitude value is captured by means of an altitude hold, or by transitioning to an FMS specified altitude, then different mode indicators are displayed. Thus, if ALT is displayed as an FMA, then

Target Source Indicator = 0 (autopilot selected altitude mode)
Vertical Mode Indicator = 1 (capture / maintaining target altitude).

Similarly, a logic translation table can be built which transforms many FMA values into Target Source and Vertical Mode Indicator values, and determines an appropriate parameter (or ARINC label on an output bus) to be used for Target Altitude. Unfortunately, this type of logic translation may not be complete and unambiguous for representing all FMS level-off conditions, and thus cannot be recommended as a sole basis for implementing full Target Altitude capability, except, for a few modern FMS aircraft models. Consequently, we recommend deferring implementation of target capability level 2 at the current time.

Target Heading / Track (element 11) can potentially come from three different sources aboard the transmitting aircraft, depending on the horizontal Target Source Indicator (element 13), i.e. horizontal *Target Source Indicator* is defined by the following values:

0 = Selected Heading or Track angle from the autopilot interface
1 = Heading / Track Hold from the horizontal guidance function (or current heading or course)
2 = FMS intended Track from a Flight Management interface or output bus.

The *Heading / Track Indicator* (element 12) is used to differentiate between heading and track angle, and is defined as:

0 = Air reference Heading Angle
1 = Ground (inertial) reference Track Angle.

The FMS intended track angle used for horizontal guidance depends on the current horizontal TCP type. For the geodesic path (straight course) path segments, i.e. CF and TF to fix types, the target track is the track-to TCP value. For the DF to fix type, target track is the current bearing angle to the lateral TCP point. For the Fly-By transition, target track is the track-to Fly-By point until the lateral turn begins, and then transitions to the track-from TCP value. Similarly, for a DF to Fly-By transition, the target track is the bearing angle to the Fly-By point until the lateral Fly-By turn begins, and then transitions to the track-from TCP value. For an RF turn transition, the target track is the track-from TCP value.

The *Horizontal Mode Indicator* (element 14) signals whether target heading/ track is being acquired (i.e., lateral transition toward the target direction is in progress), or whether the target value has been captured and is currently being maintained. The values of the Horizontal Mode Indicator are:

0 = Acquisition of target heading / track (lateral transition in progress)
1 = Capture /Holding of target heading/ track angle.

Most target heading / track parameters are uniquely characterized by autopilot states or by the horizontal Flight Mode Annunciators in an FMS or RNAV aircraft. If the aircraft is in an autopilot mode, e.g. Heading Hold or Heading Select, the FMA's identify the appropriate values for elements 12 and 13, and an appropriate target heading / track angle can then be identified for TSR reporting. Similarly, if the aircraft is flying with LNAV or RNAV engaged, then elements 12 and 13 are well defined and an appropriate target track can be computed from the lateral leg type currently being flown and the next or next+1 lateral waypoints. However, some aircraft systems may not indicate when horizontal target capture has occurred. Guidelines for computing default Horizontal Mode Indicator (element 14) using current state values and rate information will be provided in a MASPS appendix for such systems.

TCR Trajectory Data Elements

In this section we describe each of the report elements directly associated with trajectory segments and associated change points and typical data sources for creating such report elements. There are twelve~~en~~ horizontal and vertical report elements associated with each flight segment, some of which may not be required. (See section 9 for required TCP data elements for each horizontal and vertical TCP type.) These~~ ten~~ data elements are shown in Table C-2.

Table C-2: TCR Trajectory Data Elements

6	Time to Go (TTG)
8	TCP Type (Horizontal)
9a	Latitude
9b	Longitude
10	Turn Radius
11	Track to TCP
12	Track from TCP
14	Command/Planned (Horizontal)

16	TCP Type (Vertical)
17	Altitude
18	Altitude Type
22~~1~~	Command/Planned (Vertical)

Time to Go (element 6) is required for all ~~horizontal~~ change points~~ and for all vertical TCP's if available, i.e. a Target Altitude change point may not have a TTG and in this case, TCP sequencing is by altitude precedence~~. Note: TTG is normally a positive value. However, in the case of Fly-By TCP's, the TTG is referenced relative to the Fly-By point (min distance to Fly-By), and in that case, negative TTG values may be reported ~~(or alternately, no TTG values)~~ until the end-of-turn occurs and the TCR reports are sequenced.

For Revision A, *Horizontal TCP Type* (element 8) consists of the five flight segment types described in section 9. These types are coded as follows:

0 = Direct-to Fix Lateral Transition (DF leg type)
1 = Geodesic Path (Straight Course) to Fix Lateral Transition (CF and TF leg types)
2 = Fly-By Turn Transition (CF or TF to Fly-By turn)
3 = Direct to Fly-By Turn Transition (DF to Fly-By)
4 = Radius to Fix Turn Transition (RF turn)

Space is reserved for future TCP types 5 to 15. The TCP types and trajectory data are obtained directly or derived from the NAV leg types on the FMS or RNAV output bus, e.g. ARINC 702A trajectory bus. The Fix components Latitude (element 9a), Longitude (element 9b), and Turn Radius (element 10) are direct outputs from the trajectory bus, if available. The track- to TCP (element 11) is computed using the previous "from" waypoint and the "to" or endpoint waypoint, and similarly, track-from TCP is computed using the endpoint waypoint (or Fly-by point) and the next+1 waypoint. (Note: track-to and track-from can be computed on the receive side, reducing transmission bandwidth, if there is a preceding or following TCP value being transmitted.)

The horizontal *Command / Planned* flag (element 14) is set based on the TSR horizontal Target Source Indicator, i.e. if the active flight segment is being flown in an autopilot mode (TSI = 0 or 1) then all the following TCR's are Planned segments. Otherwise, if the active flight segment is being flown in an FMS or RNAV mode (TSI=2), then all the TCR's are Command segments.

There are six *Vertical TCP Types* (element 16) proposed for Revision A. These types are:

0 = Unknown Altitude Type
1 = Target Altitude
2 = Constraint Altitude (provisioning in Rev A)
3 = Estimated Altitude
4 = Top of Climb (TOC)
5 = Top of Descent (TOD)

The Unknown Altitude Type is a default value if the type of altitude is not explicitly known, e.g. target altitude, constraint altitude, etc. Target Altitude can be either an autopilot specified value or some FMS limit altitude. (If a Constraint Altitude is specified, then the constraint attributes (elements 19~~8~~ and 20~~19~~) must also be specified.) Estimated Altitude is the value estimated ~~by~~ the FMS when transiting a lateral fix during a climb or descent transition. Top-of-Climb and Top-of-Descent are FMS estimated TCP's that delimit the end of climb / beginning of cruise point and the end of cruise / beginning of descent point. The Altitude parameter (element 17) is either an autopilot target value or an FMS specified altitude. Altitude Type (element 18) is either an MSL value or a Flight Level, and is determined as described above for TSR's.

The Vertical *Command / Planned* flag (element 22~~1~~) is set based on several possible circumstances. If the active flight segment is being flown in an autopilot mode (vertical TSI = 0 or 1) then all the following vertical TCR's are Planned segments. Otherwise, if the active flight segment is being flown in an FMS VNAV mode (TSI=2), then the initial TCR is a vertical Command segment. Subsequent TCR's are also Command segments, unless there is a Target Altitude TCP type. If one of the TCR's has a Target Altitude Type that corresponds to an autopilot Selected Altitude, then that TCR is a Command segment, and all subsequent TCR's are Planned segments. (See Table 6 for an example of the latter case.)